

NASA Technical Memorandum 4126

Automation and
Robotics

Communications

NASA Information Sciences and Human Factors Program

Computer
Sciences

Annual Report, 1988

Controls and
Guidance - Aeronautics

Controls and
Guidance - Space

JULY 1989

Data Systems

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Human Factors -
Space

Sensor Systems

NASA Technical Memorandum 4126

**NASA Information Sciences and
Human Factors Program**

Annual Report, 1988

**NASA Office of Aeronautics and
Space Technology**

**Information Sciences and Human
Factors Division**

**National Aeronautics
and Space Administration**

**Scientific and Technical
Information Division**

1989

INTRODUCTION

The Information Sciences and Human Factors (IS&HF) Division is one of five divisions that comprise NASA's Office of Aeronautics and Space Technology (OAST). This division sponsors research in both aeronautical and space technology. This annual report documents the most significant accomplishments during the past year. Each year, the annual report is prepared to serve as the primary mechanism for coordinating NASA activities with industry and industrial IR&D managers. This document is also intended to communicate significant technical accomplishments to NASA technologists, project engineers, other government agencies and academia.

The IS&HF Program consists of seven major elements: Automation and Robotics, Computer Sciences, Communications, Controls and Guidance, Data Systems, Human Factors, and Sensor Technology. Accomplishments are presented in all seven categories: Controls and Guidance and Human Factors are shown in two sections, Space and Aeronautics. Total program funding, including civil service manpower costs, for FY89 is shown below.

<u>Element</u>	<u>Aero (\$M)</u>	<u>Space (\$M)</u>	<u>Total R&D(\$M)</u>
Automation and Robotics		42.7	42.7
Communications Systems		11.5	11.5
Computer Science	7.0	6.1	13.1
Controls & Guidance	47.3	10.0	57.3
Data Systems		12.9	12.9
Human Factors	14.8	7.9	22.7
Sensor Technology		17.5	17.5

The NASA Civil Space Technology Initiative (CSTI) was initiated in FY88 with the goal of revitalizing the nation's civil space technology capabilities and enabling more efficient, reliable and less costly space transportation and earth orbit operations. The IS&HF Division has focused CSTI technology activities in High Speed/Capacity Data Systems, Science Sensors, and Automation and Robotics. Funding for these activities are included above. In FY89, another new activity, Pathfinder, is being initiated. The objective of the Pathfinder Program is to develop and validate critical enabling technologies for future exploration missions. Pathfinder initially includes focused Information Sciences and Human Factors elements in Planetary Rover Technology, Human Factors/EVA suit, Automated Rendezvous and Docking, and Adaptive Hazard Avoidance Landing.

Within the Base Aeronautics Human Factors Program, focused efforts in Aviation Safety/Automation are being initiated in FY89. The objectives of this program include the development of human-centered automation concepts for use in future transport aircraft and air traffic controller stations. The integration of highly automated aircraft into the future air traffic control system will also be addressed in this program augmentation.

To aid in the communication of program efforts, the names and phone numbers of headquarters program managers are included in this report along with the names and phone numbers of the key center technologists who conducted or managed the significant technology activities.

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NASA DIRECTORY

<u>Center</u>	<u>Symbol</u>
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Ames Research Center Dryden Flight Research Facility PO Box 273 Edwards, CA 93523	DFRF
Goddard Space Flight Center Greenbelt, MD 20771	GSFC
Headquarters NASA/OAST/RC Washington, DC 20546	HQ
Jet Propulsion Laboratory 4800 Oak Grove Drive Pasadena, CA 91109	JPL
Lyndon B. Johnson Space Center Houston, TX 77058	JSC
John F. Kennedy Space Center Kennedy Space Center, FL 32899	KSC
Langley Research Center Hampton, VA 23665	LaRC
Lewis Research Center 21000 Brookpark Road Cleveland, OH 44135	LeRC
George C. Marshall Space Flight Center National Aeronautics and Space Administration Marshall Space Flight Center, AL 35812	MSFC

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Automation and Robotics

OAST created the Civil Space Technology Initiative (CSTI) to improve NASA space technology. Of particular concern has been the cost of NASA ground and flight operation, such that the CSTI program has focused significant resources on development and demonstration of automation and robotics technologies for space applications. Artificial intelligence and Telerobotics when applied to the space environment have the capability to significantly improve productivity and enhance safety, as well as reduce the cost of NASA operations.

The automation and robotics program is divided into two areas, with the Autonomous Systems focusing on automation for in-space servicing, assembly, and repair. Applications demonstrations are planned at NASA mission centers for the transfer of the technology into the operations environment. Underlying the demonstrations are five research areas that will develop expertise in: sensing and perception; planning and reasoning; control execution; operator interface; and systems architecture and integration. Coordination with DARPA's A & R program is achieved since NASA acts as a DARPA agent.

FY85 saw the establishment of the A & R program. The Telerobotics Program has achieved its first major technology demonstration through the vision-based de-spin of a spinning satellite (once it is initialized by a human-guided graphic overlay). Three applications demonstrations were completed using the Beam Assembly Teleoperator. The applications were: assembling beam elements into a space structure; using a general control structure for coordinated movement of multiple robot arms; and using the Oak Ridge National Laboratory's teleoperated manipulator to recreate the Access experiment. The Autonomous Systems Program has progressed towards the Space Station Thermal Control Expert System technology demonstration. We have developed an operational readiness prototype expert system for the monitoring of the Shuttle communications systems and initial integration of the KATE and GMODS for diagnostics and control of the Shuttle Environmental Control System. Also, we developed an expert system for aiding the communications officer in the Shuttle Mission Control Room which was first operationally used on STS 26.

Major research goals were accomplished in the areas of: operator interface; systems architecture and integration; and planning and reasoning. In the operator interface element higher-performance force reflecting hand controllers and triggers were tested for teleoperation. In the systems architecture and integration element, the first design of the spaceborne symbolic processor was completed with a reconfigurable, radiation resistant, fault-tolerant architecture. In the planning and reasoning element, a collaborative effort with DARPA began on research of intelligent communicating agents while the Autoclass probabilistic reasoning system produced striking new classes of spectral objects when applied to IRAS data.

In addition to the CSTI technologies, OAST has been reviewing the technology requirements for future planetary and lunar missions, and has packaged these into the new initiative called Pathfinder. In the area of exploration a significant amount of automation and robotics research will be focused on the development of a planetary rover that would act in the place of humans in the scientific discovery of the moon and Mars semi-autonomously, with only occasional communication and direction from Earth. This is a challenging problem in that

the rover would effectively be a mobile laboratory with its own instrumentation, tools and intelligence for self-navigation, and rock sample acquisition and analysis. This development effort is a requirement unique to NASA, and it will build on the in-house expertise in automation and robotics that has resulted from the CSTI program.

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Integrated Communications Officer (INCO) Real-Time Expert System Project

NASA is currently facing the demands of operating several long-lived space projects such as Space Shuttle and the Space Station. The operational lifetime of these projects is twenty years or greater. With normal attrition of operations personnel, it is a challenge to assure the quality of flight decision-making over the entire lifetime of these programs. NASA's unique bimodal age distribution, the result of personnel freezes between Apollo and Shuttle, makes this an even greater challenge as large numbers of NASA's most experienced personnel will soon be eligible for retirement.

NASA must develop technologies to capture the corporate knowledge of experienced personnel into automated mission operations systems in order to maintain the quality of flight decision-making. Real-time expert system technology has been developed by OAST with the goal of providing tools for automating mission operations. The Integrated Communications Officer (INCO) Expert System project's goal is to demonstrate that these technologies are ready to be used in a substantial way in real NASA mission operations. The INCO Expert System Project takes real-time expert systems technology out of the laboratory and places it in a real space mission operations environment.

In specific, the INCO project attempts to automate fault detection in the Space Shuttle's communication and instrumentation systems. It shows a flight controller at the current mainframe computer console monitoring a shuttle simulation. Note that the displays are monochrome and the flight controller has a complex assortment of status lights to assess. The expert system workstation display unit is located next to the conventional console. This enables us to test and evaluate the expert system in parallel with the conventional system. The expert system evaluates information and draws the operators attention to detected failures by the use of color graphic schematics, which are animated with telemetry data.

Development of the INCO Expert System project started in August 1987, was demonstrated in the laboratory environment in January 1988 and moved to Flight Control Room 1 in the Mission Control Center in April 1988. The system has been used extensively in simulations in preparation for the STS-26 flight. In one simulation, the INCO mainframe console failed and the flight controllers relied entirely on the expert system workstation displays to conduct the simulation. In another simulation, the entire mainframe computer complex failed and INCO and Main Engine flight controllers used data displayed by the INCO Expert System to make flight-critical ascent decisions.

These experiences have directly resulted in a decision by Mission Operations Directorate to expand the technologies developed by the INCO Expert System Project to provide an automated data monitoring capability in seven additional areas, which include electrical power, mechanical systems, life support and thermal monitoring.

The system will be used during the STS-26 flight in an advisory mode and will monitor telemetry and notify flight controllers when it detects fault. After STS-26, one of the monochrome mainframe display monitors will be removed from the INCO console and replaced by the INCO Expert System display unit. This will be the first time that mainframe monitors have been removed from the MCC.

TECHNICAL CONTACT: John F. Muratore, JSC (713) 483-0796

INTEGRATED COMMUNICATIONS OFFICER (INCO) REAL-TIME EXPERT SYSTEM



Power System Autonomy Demonstration

The LeRC participation in the 1990 Systems Autonomy Demonstration Project (SADP) managed by ARC has two primary thrusts. The first is to demonstrate the coordinated operation between the knowledge-based controllers of the Space Station Electrical Power System (EPS) Testbed at LeRC and the Space Station Module/Power Management and Distribution (SSM/PMAD) Testbed at MSFC. This includes the development of the knowledge-based Power Management and Control System (PMACS) with its Autonomous Power Expert (APEX) to provide the capability to autonomously operate the EPS Testbed at LeRC first in a stand-alone mode, then in a coordinated mode with the SSM/PMAD Testbed at MSFC. The second is the execution of the 1990 SADP test scenarios that demonstrate the additional coordination of the LeRC/MSFC knowledge-based controllers with the Thermal Control System (TCS) and the Data Management System/Operations Management System (DMS/OMS) Testbeds at JSC via the SADP intercenter communications network (SADPnet).

On the Space Station the EPS will play a key role in coordinated operating modes with the other on-board systems supplying the primary electrical power/energy upon which all other systems and experiments must rely for their proper functioning. Therefore, the EPS PMACS will place special requirements upon and will have a critical interface with the executive controller. Because of the EPS's unique and complex interactive roles with each of the various Space Station systems, it has potential for increased reliability and operational cost reductions from the application of the autonomy core technologies. Development, application and demonstration of these technologies for the EPS will represent a major contribution to the goals of the OAST Automation and Robotics Program.

6

The demonstration will involve the execution of a multi-event test scenario by the autonomous knowledge-based controllers including simulation of the typical sequence-of-events schedule between the several systems. During the simulation, faults will be generated in one or more of the testbeds and the knowledge-based controllers will be activated to resolve the resulting anomalous operation.

Primary emphasis at LeRC will be focused on detection/classification of faults, isolation and reconfiguration of the EPS and its user loads to near optimum power utilization in response to a specified number and type of faults. Two other major initiatives will include planning and scheduling for energy/power dispatching between the LeRC EPS Testbed and the MSFC SSM/PMAD Testbed and integration of knowledge-based with conventional automation into the design and real time control of Space Station Testbeds.

LeRC has assembled a highly matrixed team of experts including knowledge engineers, and electrical power/energy resource management and scheduling experts from four divisions under the Aerospace Technology and Space Station Directorates. Two artificial intelligence/expert system workstations have been installed with development shells and software for knowledge-based prototyping. The existing fault tolerant architecture and real-time control of the EPS Testbed and its modeling and simulation algorithms are being analyzed by the LeRC team in order to implement the PSAD Stand-Alone Tests and the subsequent coordinated tests with the MSFC and JSC Testbeds in 1989 and 1990, respectively.

TECHNICAL CONTACT: Gale R. Sundberg, LeRC, (216) 235-1420

CSTI SYSTEM AUTONOMY DEMONSTRATION PROGRAM

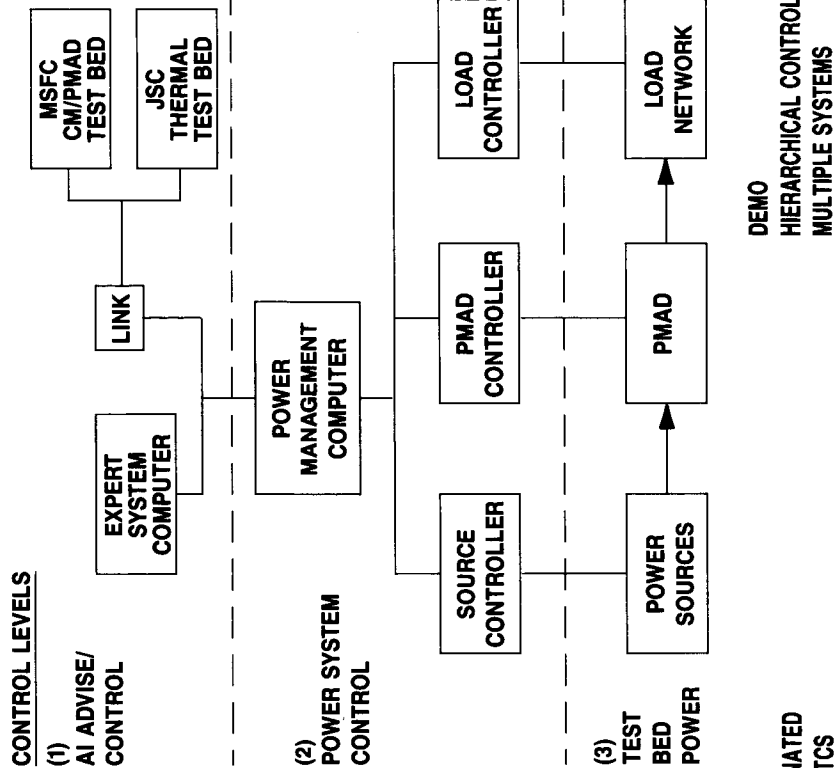
GOAL:

DEMONSTRATE COORDINATED CONTROL OF TWO AUTOMATED SUBSYSTEMS (ELECTRICAL POWER SYSTEM AND THERMAL CONTROL SYSTEM). AND TO APPLY OAST AUTOMATION TECHNOLOGY TO SS EPS/TCS TESTBEDS.

APPROACH:

- ACCESS TO EPS-CM/PMAD DOMAIN EXPERTS
- USE 20 KHz SS PMAD TESTBED
- POWER/ENERGY RESOURCE ALLOCATION PLAN/SCHEDULE
- EPS FAULT DIAGNOSTICS/CONTINGENCY
- SYSTEM STATE RESTORATION
- INTEGRATE FAULT TOLERANT AND CORE TECH
- LINK TO TCS AND CORE MODULE

PSAD POWER TEST BED CONTROL HIERARCHY



88	89	90	91	92	93
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Telerobot Interactive Planning System

The Telerobot Interactive Planning System is the primary operator interface to the autonomous capabilities of the telerobot. It also performs high-level task planning and dynamically recovers from failures (selects alternative actions) in autonomous robot operations. The operator can "coach" the planner during task execution.

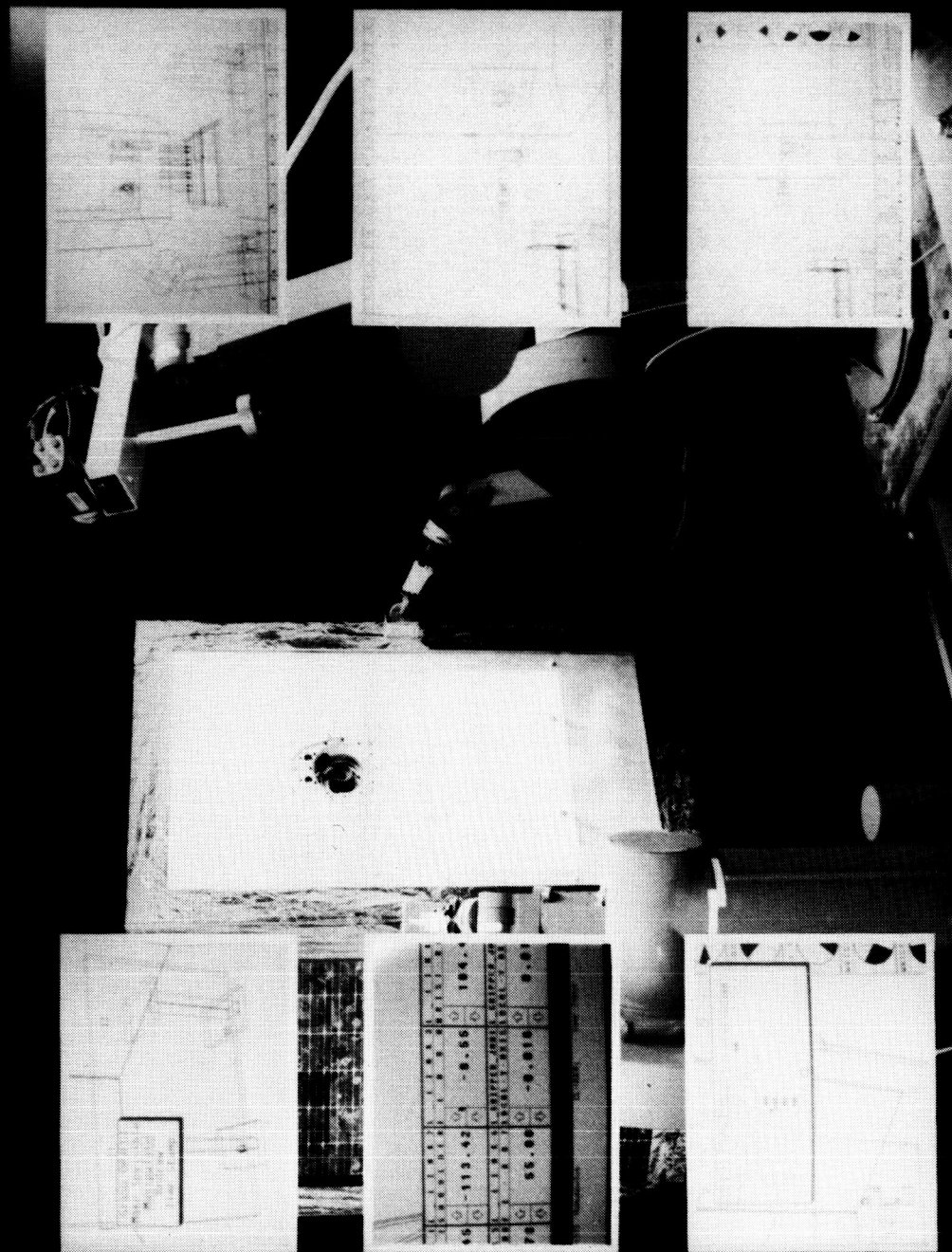
In space, transmission time delays between the operator and the manipulators mandate that telerobots capable of both teleoperation and autonomy be developed. The technological needs are to support handoff of control between teleoperation and autonomous operation and to provide the operator with supervisory control of autonomous operation.

High-level planning has been integrated into the telerobot architecture. Dynamic recovery from manipulation errors has been demonstrated. An operator interface providing interactive supervisory control has been developed.

The Telerobot Interactive Planning System was developed and partially integrated into the JPL Telerobot Testbed. It consists of a task planner, a graphics simulator, and a spatial planner. The planning and simulation of the replacement of a satellite module was successfully demonstrated.

FY89 Plans are to complete integration of systems into Telerobot, research deeper machine reasoning on robotic manipulation and feedback, and develop a user interface to robotic task plans.

TELERBOT INTERACTIVE PLANNING SYSTEM



MANUAL

AUTOMATIC

RC89-348(3)

Automated Satellite Grappling

Satellite grappling was part of the core demonstration of the NASA Telerobot Technology Testbed. It utilized the Sensing & Perception (S&P) Subsystem, consisting of three cameras, custom image processing hardware, a MicroVAX II computer, and the Manipulators and Control Mechanization (MCM) Subsystem, consisting of two MicroVAX II computers and two PUMA robot arms. Satellite position, orientation, velocity and angular velocity from visual tracking was sent from the S&P Subsystem to the MCM Subsystem, which in turn grappled the satellite mockup, damped its motion, and brought it to the desired position using compliant control of the two robot arms.

Automated satellite grappling is useful for orbital servicing to grapple or dock with a spacecraft that may be in uncontrolled motion, especially where the motion is too fast to allow teleoperation to work.

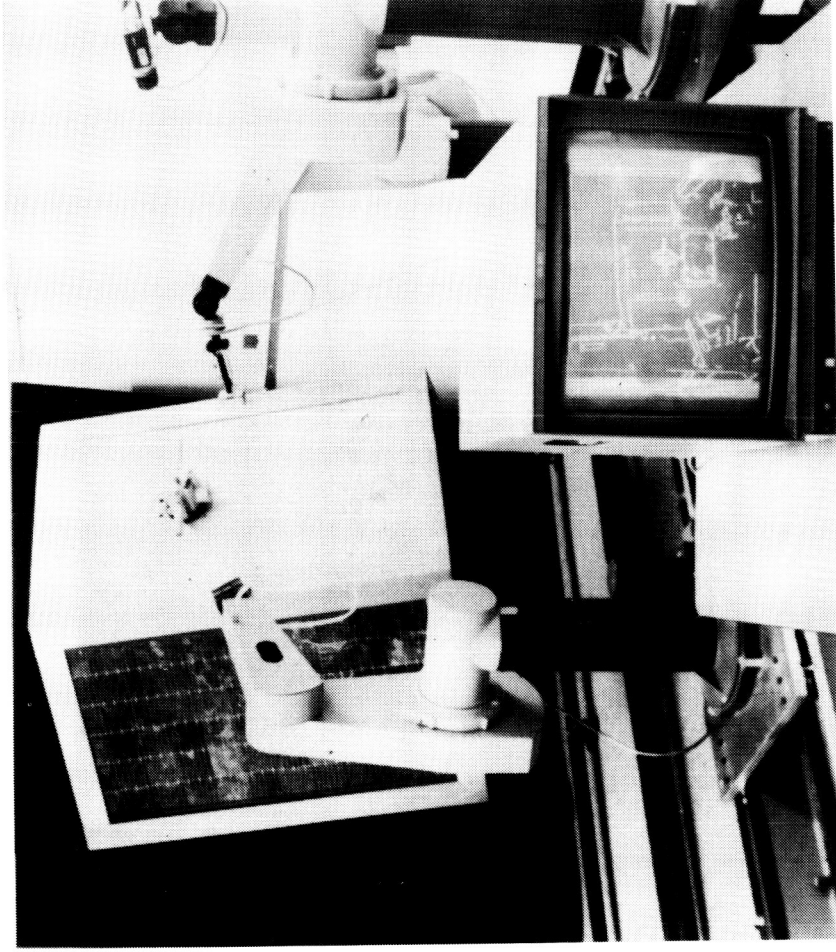
The recent core demonstration showed that real-time, model-based optical tracking of a complex, unlabelled object is practical using some custom image processing hardware and off-the-shelf, inexpensive computers. It was the first demonstration of this type of visual tracking integrated with compliant control of manipulators for grappling a moving object.

The technology used is applicable to tracking, verification, and manipulation of objects in any robotic context, including navigation, approach & docking, tool manipulation, etc.

The 1988 core demonstration included 2-arm grappling of satellite mockup spinning at 1 rpm. Follow-on work will enable the system to deal with more complex objects, and add the capability to automatically acquire the object to be traced, as well as the operational capability to grapple satellites spinning at higher speeds.

TECHNICAL CONTACT: B. Wilcox, JPL (818) 354-4625

NASA AUTOMATED SATELLITE GRAPPLING



- CUSTOM HARDWARE EXTRACTS EDGES AT FULL VIDEO RATE
- VISION COMPUTER TRACKS SATELLITE POSITION AND ORIENTATION IN REAL TIME
- ROBOT MANIPULATORS GRAPPLE MOVING SATELLITE AND BRING IT TO A HALT

Advanced Bilateral Teleoperation System

This breadboard system currently consists of: (1) a six degree-of-freedom (dof) PUMA 560 robot arm; (2) a JPL smart robot hand on the robot arm equipped with a six dof force-moment sensor, grasp force sensors and local processing and control electronics; (3) a six dof generalized Force-Reflecting Hand Controller (FRHC); (4) two computing nodes for control and information display, one at the robot site and one at the FRHC (control station) site; and (5) computer graphics terminal at the control station site. The computer graphics terminal utilizes a PARALLAX graphics board to generate real-time graphics display of force-moment and grasp force information and an IRIS graphics workstation to generate a real-time perspective graphics image of robot arm motion. Some of the key points in this laboratory system are the data handling and computing architecture, the communication method, and the handling of mathematical transformations. The architecture is a fully synchronized pipeline.

This technology provides intelligent (task-level) and easily adjustable tools to astronauts or ground operators of space telerobots; and efficient and robust computing system for telerobot control.

This end-to-end system elevates teleoperation to a new level of capabilities via the use of sensors, advanced computations and communication methods, and real-time graphic displays. It provides multi-mode manual control in the task space (position, rate, hybrid position/rate, hybrid position/force control) from the same device, and the same device can be used for the control of various robot arms through software modification. FRHC commands can easily be indexed, can be restricted to selected task space dof, or can be shared with sensor or model referenced automatic control algorithms in selected task space dof. The FRHC can also be used for motion planning or teaching.

Both space and terrestrial applications are possible. The Universal Motor Control (UMC) is already duplicated by several companies in the U.S. Several NASA and non-NASA sources inquired about overall system duplicates. Part of the system is a candidate for flight experiment (TRIIFEX).

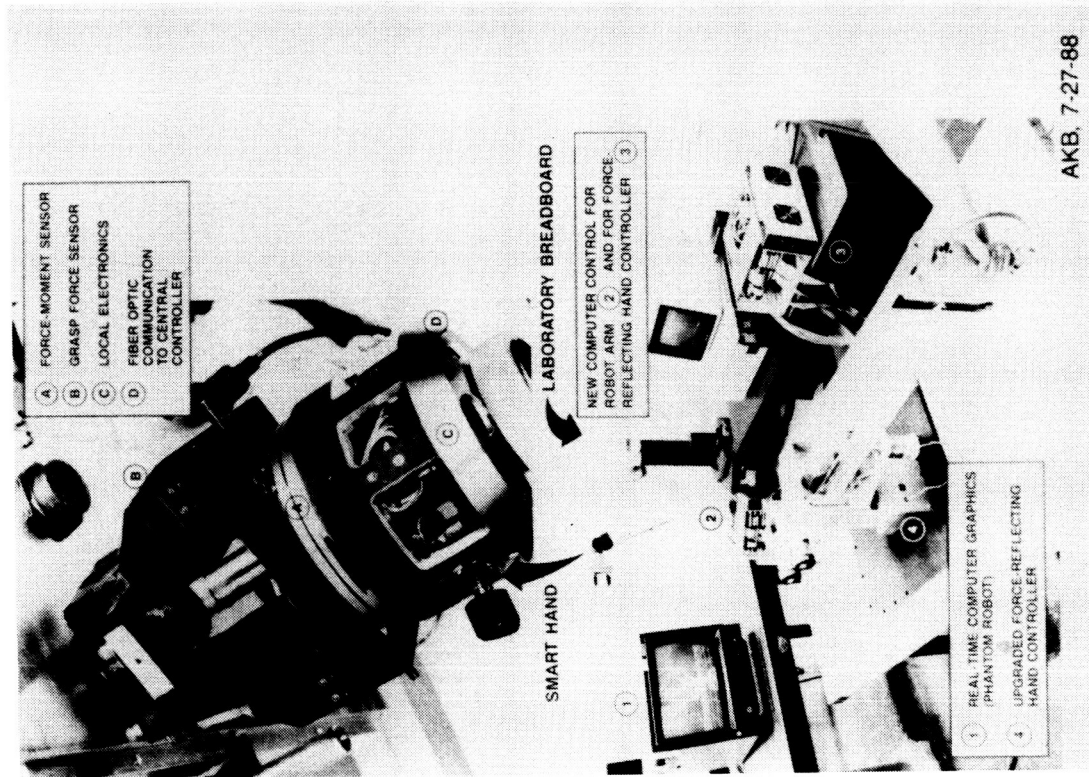
The current system has been tested and used in operator control experiments over 100 hours at JPL in this year. System extension to dual-arm control is in progress. Plans are in development for upgrading sensing, processing, and communication capabilities to create a progressively more intelligent control for advanced teleoperations.

TECHNICAL CONTACT: A. Bejczy, JPL (818) 354-4568
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ADVANCED BILATERAL TELEOPERATION SYSTEM

- SIX-AXIS ROBUST AND COMPACT ROBOT CONTROL SYSTEM WITH FORCE-REFLECTING OPERATOR INTERFACE
- ENABLES TASK-LEVEL AND SHARED MANUAL-COMPUTER CONTROL OF TELEROBOTS
- TELEOPERATION IS ELEVATED TO NEW LEVEL OF INTELLIGENT CAPABILITIES VIA SENSORS AND ADVANCED COMPUTATION AND COMMUNICATION METHODS
- BOTH SPACE AND GROUND APPLICATIONS ARE POSSIBLE, INCLUDING TERRESTRIAL INDUSTRIES
- SYSTEM TESTED IN WELL OVER 100 HOURS CONTROL EXPERIMENTS
- SYSTEM EXTENSION TO DUAL-ARM TELEOPERATION IS UNDER WAY WITH EXPANDED SENSING CAPABILITIES



AKB. 7-27-88

Traded and Shared Control of Manipulators

The purpose of this project was to design and implement a robotic control system to perform teleoperated and autonomous task executions with frequent trading and sharing of control between these modes of operations. In the shared mode of control, a task is performed simultaneously by an operator and the autonomous controller to take advantage of the best capabilities of the two modes of control.

Space assembly and repair operations require dexterous manipulation of objects with one or more manipulators. Control strategies developed for well structured repetitive industrial applications cannot be utilized for non-repetitive unstructured space tasks. The latter requires rich sensor-based robot controllers that are insensitive to local-remote time delays and are capable of recovering from failures.

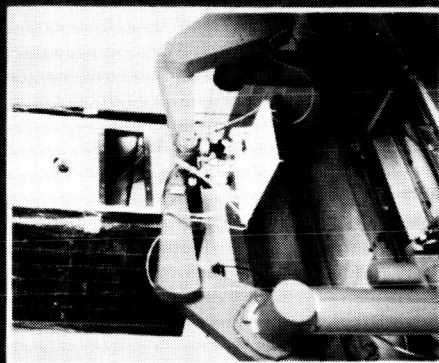
Non-repetitive, unstructured robotic task executions required human intervention in various levels of control. Certain portions of these tasks are best accomplished by a human operator performing task planning and maneuvering the robots in cluttered environments. Many tasks require contact to be made between the robot and the environment, such as in an insertion process. Due to the time delay between the operator-generated commands and the robot in a remote location, these tasks are best accomplished by a remote autonomous robot controller. The main elements of this technology are: advance teleoperation and autonomous robot control; computing hardware and software; and high level robot manipulation primitives.

Laboratory experimentation with realistic space-like hardware will be undertaken to demonstrate the dexterity and fault recovery of the control system. The test hardware will be selected based on actual needs of NASA space operations such as Space Station, Earth Observation System, Space Shuttle, and satellite servicing.

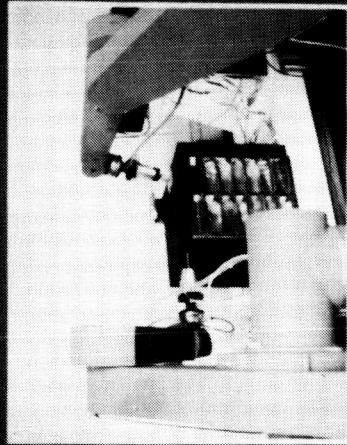
A first generation of a robot controller with limited force control, dual arm control, and traded control capabilities has been developed. More advanced control laws are being developed and tested using simulation techniques. A multi-processor computing environment is under development to host the advanced control laws and implement high bandwidth teleoperation for the development of shared control strategies. Research is also in progress on the development of control strategies for 7 dof robots, in support of the Flight Telerobotic Servicer (FTS) project.

TECHNICAL CONTACT: S. Hayati, JPL (818) 354-8273

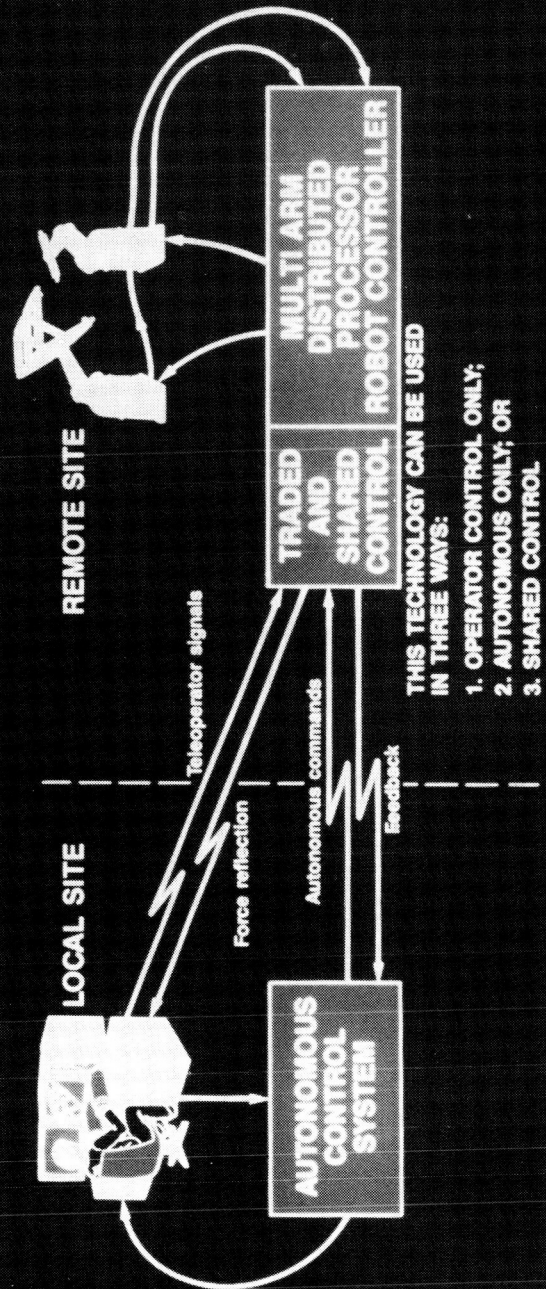
TRADED AND SHARED CONTROL OF ROBOT MANIPULATORS



SATELLITE
MOCKUP
PANEL
REMOVAL
TASK



REALISTIC SPACE-LIKE
LABORATORY EXPERIMENTATION



Telerobot Technology Testbed: Core Demonstration of Robot Control

Through a phased set of ground-based demonstrations the telerobot testbed project shows an evolving capability to usefully complement, significantly enhance, or replace manned space activities. By integrating advanced sensing, robotic manipulation and AI-based control under human-interactive supervision, the testbed can show telerobotic execution of a variety of mission tasks including space assembly, maintenance, repair and telescience. This human-machine synergism has the potential to increase astronaut productivity by reducing EVA hours, reduce cost and risk as a consequence, and extend mission capability and reliability.

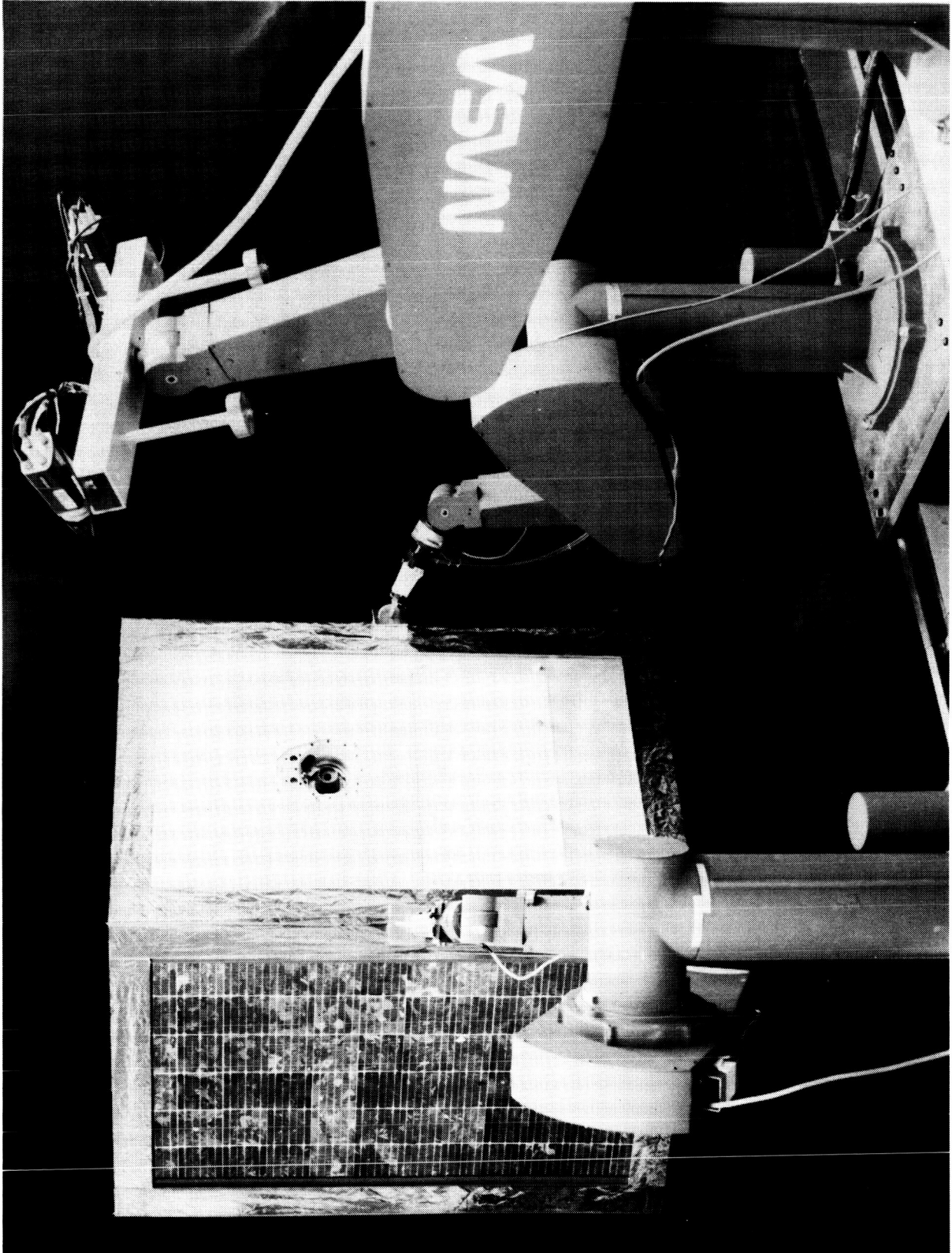
The telerobot testbed has been initially focused on the development of the robotic elements of the system. These elements include: 1) machine vision for automatic tracking of a rotating object and verification of the location of objects in the workcell; 2) control mechanization of two 6 dof robots through hybrid position/force control and master/slave dual arm position control; 3) development and demonstration of adaptive control schemes on a 6 dof robot; 4) run-time command and control of a robot in the performance of prototype tasks, including collision detection and fine motion planning; and 5) expert planning system supporting the execution of the prototype tasks through task organization and resource allocation.

The demonstration of the integration of these elements has been conducted in a facility containing three 6 dof robot arms, two of which are mounted on a movable lathe bed, and a task board that can be oriented and repositioned. The tasks demonstrated in this facility were bolt release, hinged door opening, tool exchange, turning a crank. Within these tasks: a tool was seated to a 0.5 in. bolt to an accuracy of 0.04 in.; the bolt was released by turning the bolt/tool 10 turns, applying torques of up to 15 in. lb.; the handle of a door was located to an accuracy of 0.08 in., the handle grasped within a clearance tolerance of +/- 0.1 in.; the door/arm combination was moved through a constrained arc of over 75 deg.; a crank was located in orientation to an accuracy of 0.006 deg.; and the crank was grasped and turned in a constrained arc of 30 deg.

Using another task board in the facility, a demonstration of the autonomous tracking and grapppling of an unlabeled satellite was performed. The satellite position was determined by the tracker to an accuracy of 0.2 in. The arms grappled and damped the motion of the 400 lb satellite rotating at 1 rpm.

TECHNICAL CONTACT: D. Smith, JPL (818) 354-9277

TELEROBOT TECHNOLOGY TESTBED



Telerobot Intelligent Interface Flight Experiment (TRIIFEX)

TRIIFEX is a potential flight experiment that would be flown in conjunction with the West German Robot Technology Experiment (ROTEX) on Spacelab D2. NASA would supply a Force Reflecting Hand Controller (FRHC) that would be used alternately with the German robot controller to perform various tasks with the German robot arm as well as a graphic display of the forces and torques experienced by the arm. The experiment has two parts, the first of which is space-based where the FRHC and the operator are in microgravity, and the second is ground-based with the FRHC located in a ground station. The first experiment addresses the question of operator performance with real-time feedback, while the second addresses the question of operator performance with time delay.

Space telerobotics is a major thrust of the NASA program. Telerobotics will be vital to the Space Station, to future satellite servicing operations, to planetary exploration, and to a variety of other NASA missions. This is a vital new technology and, while much is being done in various laboratories across the nation, there are many questions that can only be addressed in flight experiments. Flight opportunities have been severely limited, and are likely to remain restricted for the foreseeable future. The proposed experiment presents a unique opportunity to take advantage of an already manifested experiment to generate data vital to other ongoing NASA programs such as the Flight Telerobot Servicer.

The TRIIFEX experiment will address the effect of sensory feedback (visual and force-moment) on an operator's ability to perform various remote tasks. For many years NASA/JPL has been developing force reflecting hand controllers and graphic displays of robot forces and torques, which ground tests indicate should enhance operator ability to perform a variety of complex tasks in space. Ground tests, however, cannot simulate robot arm dynamics in a microgravity environment, nor can they properly simulate operator neurophysical response (in microgravity). Additional questions are raised if the operator is ground-based, where time delay in the transmission of the feedback data may diminish the value of sensory feedback. The TRIIFEX experiment is designed to address all these questions. The JPL technology represents the present state of the art in such devices, and can be rapidly brought to a flight-ready status. TRIIFEX gives NASA the opportunity to garner valuable data at minimum cost and at an early date, which could guide other NASA development programs.

The Phase A study, conducted this year, showed the feasibility of the proposed experiment and defined the required interfaces with the ROTEX equipment and the D2 Spacelab. The primary question raised by the study concerned the tightness of the schedule, which was based on an assumed flight date of July 1991. That flight date has now moved back to December 1991, which appears much more feasible. NASA has now instituted a Detailed Concept Design Study for this experiment and has formally requested that the Germans consider the inclusion of the TRIIFEX on the D2 mission.

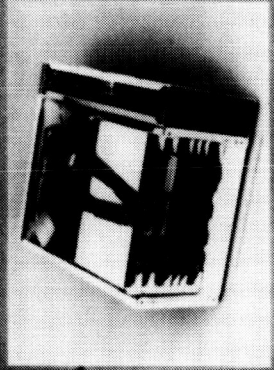
TECHNICAL CONTACT: D. Kerrisk, JPL (818) 354-2566

TELEROBOTIC INTELLIGENT INTERFACE FLIGHT EXPERIMENT (TRIIFEX)

OPERATOR ONBOARD

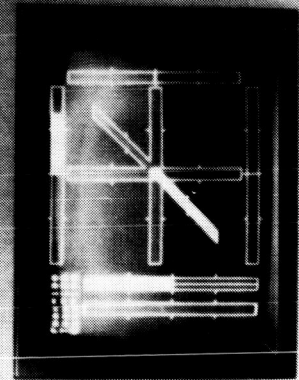
ROTEX RACK

- TELEMANIPULATION (TM) ELECTRONICS
- POWER SUPPLY UNIT
- STEREO DISPLAY
- EXPERIMENT TASKBOARD
- SMART END EFFECTOR MANIPULATOR
- ROTEX RATE CONTROLLER



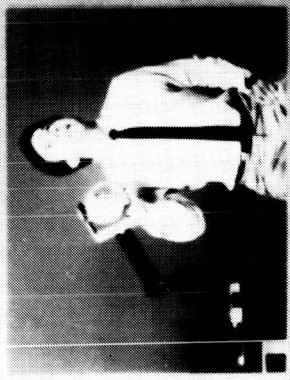
**JPL CONTROL ELECTRONICS
AND COMPUTER**

**SPACELAB D2
INTERNAL CONFIGURATION**



**FLUID TO BE
RETAINED**

**ADJUSTABLE
RIGID WAIST
RETENTION
FOR TRIIFEX**



**TELEOPERATOR
FLIGHT SUIT**

Ground Data Systems Automation Demonstration

The objective of this project is to develop AI technologies that enhance the multi-mission capabilities of ground data systems for spacecraft and scientific instruments. This system will provide automated tools for real-time and nonreal-time spacecraft and ground data systems analysis. A long-term objective is to develop technology that enables integration of uplink and downlink operations.

Increased levels of automation in mission operations are required to meet current and future project requirements. This task will demonstrate a significant reduction in operational costs and facility space requirements through increased accuracy of monitoring and analysis, remote operation of scientific instruments and improved capture of scientific data.

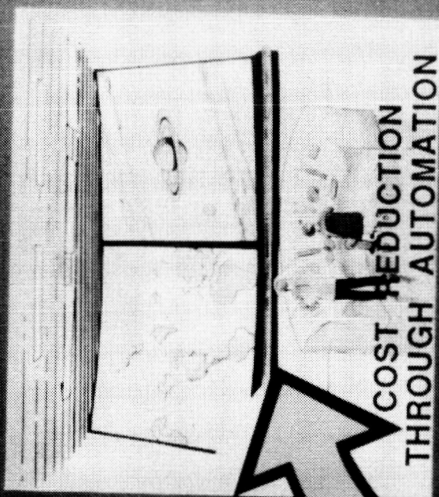
The element of the System Autonomy Program will demonstrate AI technology in a highly visible, real-time, space flight operations setting. New technological approaches will enable rapid fault detection, isolation, and recovery recommendations for spacecraft, instrument, and ground data system failures. Powerful on-line user interface tools for data analysis and prediction will result in additional capabilities, increased accuracy of monitoring and analysis, and faster response to critical events.

The planned series of demonstration products will establish a foundation for autonomous systems in multi-mission operations. The approach is directly applicable to current and planned planetary spacecraft projects including Voyager, Galileo, CRAF, Mars Observer, and MRSR.

The first planned demonstration will include automated monitoring, diagnosis, and failure recovery recommendation for at least two subsystems onboard the Voyager II spacecraft. The demonstration is planned for August 1989 during Voyager's encounter with the planet Neptune.

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**GROUND DATA SYSTEMS
AUTOMATION DEMONSTRATION**



Predictive Monitoring System (PREMON): Systems Autonomy Program

The overall goal is the development of a system, called PREMON, that will solve the problem of monitoring a complex device in real-time. A key objective is to enhance spacecraft systems autonomy by reducing the need for human interaction in monitoring spacecraft systems.

PREMON features will increase the scientific data-gathering potential of future missions. As spacecraft become more complex, a model-based approach to monitoring will be required to maintain and expand autonomy.

Traditional approaches to monitoring are inadequate in two important areas. First, false alarms are generated because sensor thresholds are not dynamically adjustable to operating conditions. Second, sensor data volume overwhelms existing real-time data interpretation technology. PREMON addresses these issues by using an explicit model of the monitored device to do common sense reasoning about device events and the causal dependencies among them. Using the model, fault thresholds for sensor values can be dynamically adjusted to fit current conditions. Also, the number of sensors monitored can be reduced to the minimum required for reliable verification.

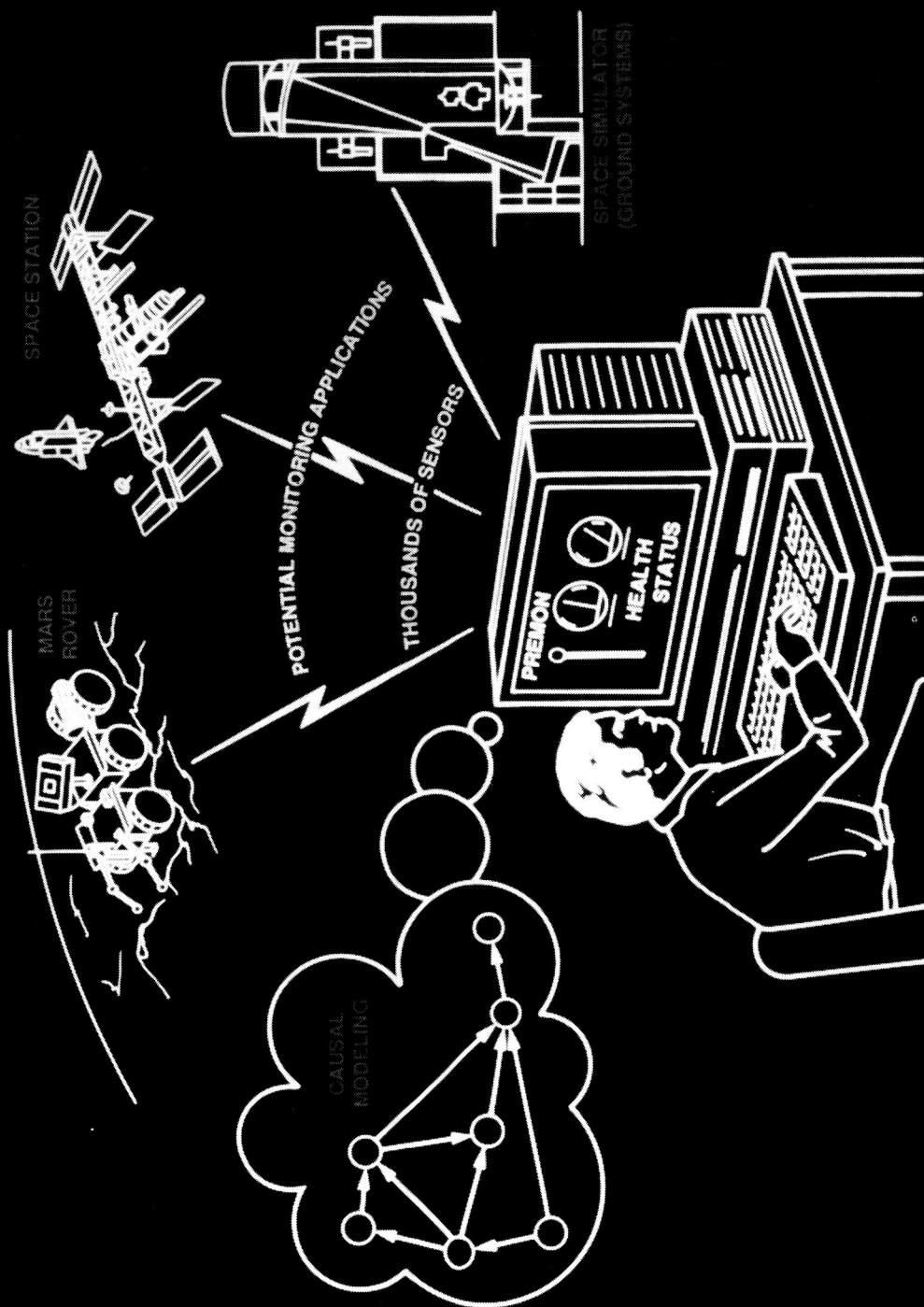
Applications for this system are the Space Simulator, Mars Rover Inclinator System, and Space Station Thermal Management System.

Thus far, the following have been accomplished in the PREMON program: 1) system architecture designed; and 2) causal simulator implemented. We plan to extend qualitative causal modeling capability and address interacting causal paths problems (funded), and develop a system to minimize the number of sensors monitored (sensor planner and interpreter).

N2

TECHNICAL CONTACT: R. Doyle, JPL (818) 354-6701

Systems Autonomy Program Predictive Monitoring System



Common Sense Reasoning, Sensor Planning, Causal Simulation

Force Control of a Multiarm Manipulator System

The research objective of this project is to extend resolved motion control laws for multiple manipulators to enable real-time coordination and control of applied forces.

For individual manipulators, force and torque can be controlled in task space in an analogous manner to, and in parallel with, resolved motion control of linear and angular velocities. In addition, positions and velocities of multiple manipulators can be controlled by referring position and rates to a common task space Control Reference Frame (CRF). However, this is not adequate for force and torque control in multiarm tasks because the force/torque requirements for each arm are not unique. Therefore, an efficient, fast method was needed for apportioning desired forces between multiple arms. The method that has been developed computes the optimum force loading for each of an arbitrary number of manipulators based on minimization of a least squares weighted sum of the desired force vector in the Control Reference Frame.

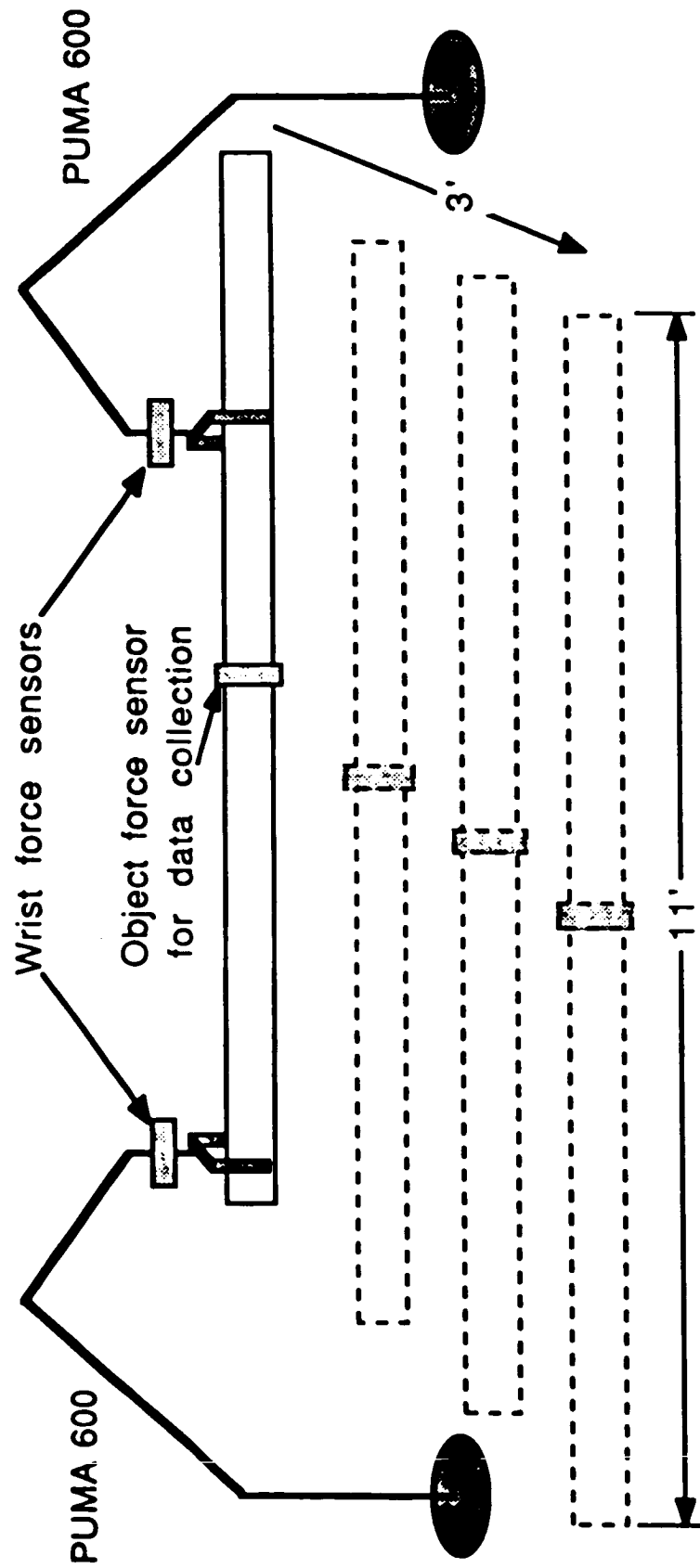
The multiarm force control system has been implemented in the Intelligent Systems Research Laboratory. When an externally applied force is desired, the new controller computes the optimum force loading for each arm, and does so at real-time speeds. The resulting load distribution tends to minimize both energy consumption and stresses applied to the manipulated object. The controller is currently being tested using an instrumented load and two robots in ISRL.

Fast, efficient control of forces is required for many multiarm robotic tasks. Because the forces are controlled in task space the controller can compensate the effects of gravity, and enable simulation of in-space telerobotic operations.

The control technique currently provides static force compensation and control. It will be tested and extended to compensate for dynamic interactions that may occur during arm motion.

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Thomas E. Alberts: LaRC (804) 864-6693

Experimental Setup



1988 Systems Autonomy Demonstration: Thermal Expert System Architecture (TEXSYS)

The 1988 SADP demonstration is designed to perform monitoring, control, trend analysis, fault detection and isolation and reconfiguration of the Boeing Thermal Testbed at the Johnson Space Center. It will demonstrate advanced AI technologies above and beyond standard expert system approaches, including causal modeling and intelligent agent reasoning incorporating goal-directed task selection, execution and monitoring.

The 1988 demonstration consists of three major modules: The TEXSYS expert system, running on a Symbolics 3650 computer; HITEX, or Human Interface to TEXSYS, running on a second Symbolics 3650 providing a powerful and flexible monitor and control station for the TEXSYS system; and, TDAS, or TEXSYS Data Acquisition System, which acts as an intelligent sensor data and control signal manager between TEXSYS/HITEX and the Thermal Testbed. TDAS receives data from the Testbed via the DACS, or Data Acquisition And Control System. Both TDAS and DACS are resident on a MicroVAX computer and communicate with the two Symbolics computers via an ethernet local area network.

Earlier work focused on the development of two preliminary research prototypes and several stand-alone system builds for experimenting with various technical approaches and design options. Current work has focused on the installation and testing of TEXSYS on the Boeing/Sundstrand design Thermal Brassboard. The current TEXSYS brassboard tests are designed to verify that the TEXSYS design can meet the overall functional and performance requirements of the 1988 SADP demonstration in real-time on actual hardware. Once completed, further work will focus on the final development and implementation of the TEXSYS system on the Boeing Thermal Testbed at the Johnson Space Center.

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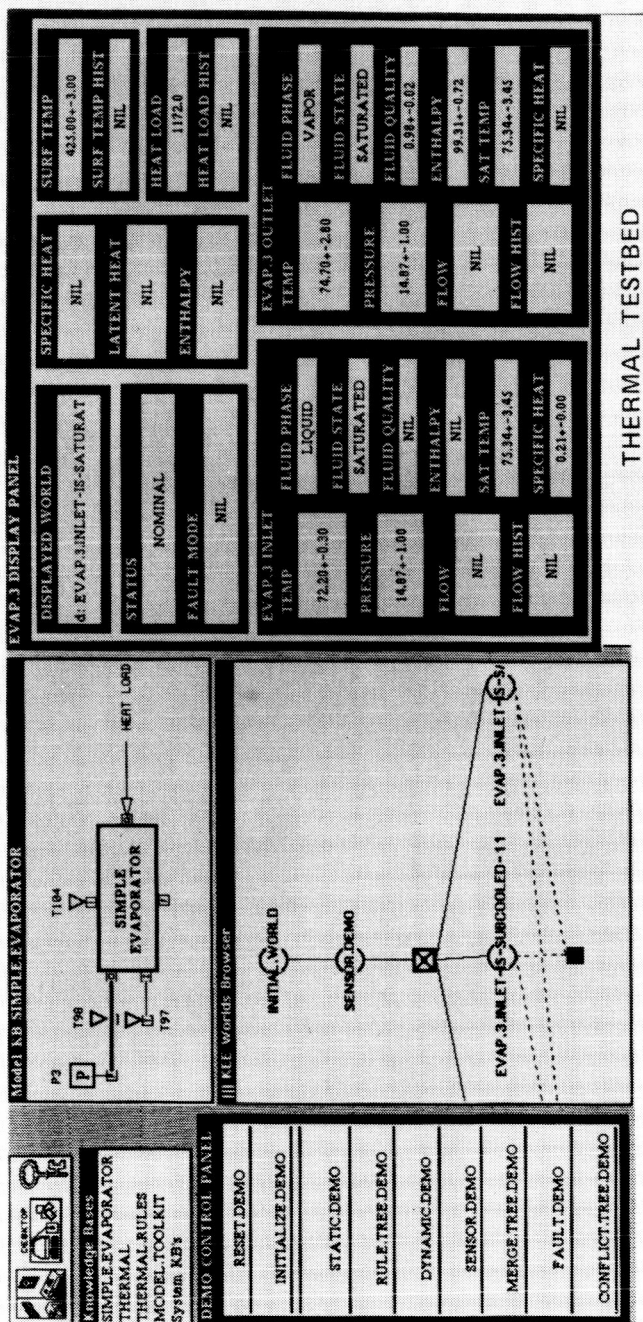
Two generic in-house developed tools are used to provide support for special AI functions. MTK, or Model Toolkit, provides support for model-based reasoning using either quantitative or qualitative techniques and heuristic or causal reasoning. XTK, or Executive Toolkit, provides a framework for building intelligent agent autonomous systems with goal-directed parallel multi-task selection and execution. Both are built to top of the KEE™ Knowledge Engineering Environment.

Additional research efforts have focused on: 1) causal modeling; 2) verification and validation methods for NASA applications of knowledge-based systems; 3) theory and design of distributed cooperating knowledge-based systems; 4) issues for real-time knowledge-based system design including rule compilation, memory management, and garbage collection. Recent work has focused on real-time issues including the development of a specialized model-based rule compiler that has yielded a 3000-fold increase in execution speed of parameter value propagation.

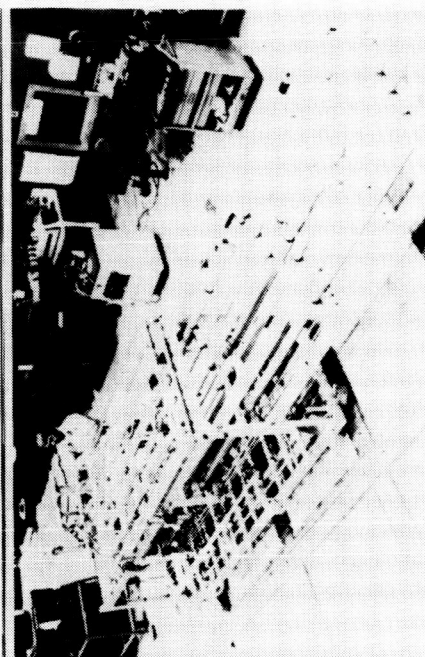
TECHNICAL CONTACT: Carla M. Wong, ARC, (415) 694-4294

SYSTEMS AUTONOMY DEMONSTRATION PROJECT

THERMAL CONTROL SYSTEM (TEXSYS)



THERMAL TESTBED



1988
AUTOMATED CONTROL OF
SINGLE SUBSYSTEM: TEXSYS
("INTELLIGENT AIDE")

- Monitor/real-time control of a single subsystem
- Goal and causal explanation displays and interfaces
- Limited fault diagnosis and trend analysis
- Qualitative and Quantitative simulation
- Reasoning assuming standard procedures
- Methodology for validation and verification of expert systems

Communications

The objective of the Communications Technology Program is to enable data transmission to and from low Earth orbit, geostationary orbit, and solar and deep space missions. This can be achieved by maintaining an effective, balanced effort in basic, applied, and demonstration prototype communications technology through work in theory, experimentation, and components.

The program consists of three major research and development discipline areas. They are: (1) microwave and millimeter wave tube component research and development; (2) solid state monolithic integrated circuit research and development; and (3) free space laser communications component and device research and development. The research ranges from basic research in surface physics (to study the mechanisms of surface degradation under high temperature and voltage operating conditions, which impacts cathode tube reliability and lifetime) to generic research on the dynamics of electron beams and circuits (for exploitation in various micrometer and millimeter wave tube devices). Work is also performed on advanced III-V semiconductor materials and devices for use in monolithic integrated analog circuits (used in adaptive, programmable phased arrays for microwave antenna feeds and receivers) on the use of electro-magnetic theory in antennas and on technology necessary for eventual employment of lasers for free space communications for future low Earth, geostationary, and deep space missions requiring high data rates with corresponding directivity and reliability.

PROGRAM MANAGER: Martin M. Sokoloski
 NASA/OAST/RC
 Washington, DC 20546
 (202) 453-2748

Reflector Distortion Compensation by Array Feeds

In response to the increasing demands placed on satellite communications systems and scientific spacecraft, large antennas are playing a major role in achieving system performance goals. Among the many different types of antenna concepts, reflectors still enjoy more acceptance among the designers of large antenna configurations. However, in the space environment the surface of these large reflectors will be distorted, resulting in a degraded antenna performance. For this reason, the development of a technique to compensate for the adverse effects of distortion will be highly desirable provided that this technique can be implemented in a cost-effective manner.

Among different possibilities, recent investigations have revealed the effectiveness of compensating for reflector surface distortions using array feeds. This approach is particularly useful in situations for which the reflector distortion is slowly varying, as is typically the case, for example, with large reflectors subject to thermal or gravitational distortions.

For the experimental study, it is assumed that the reflector surface is distorted in a fashion representing the dominant term in a typical thermal distortion. This functional expression has been used by the Optical Science Laboratory of the University of Arizona, Tucson, to fabricate a test antenna using its facility which utilizes a computer controlled milling machine to accurately contour surfaces.

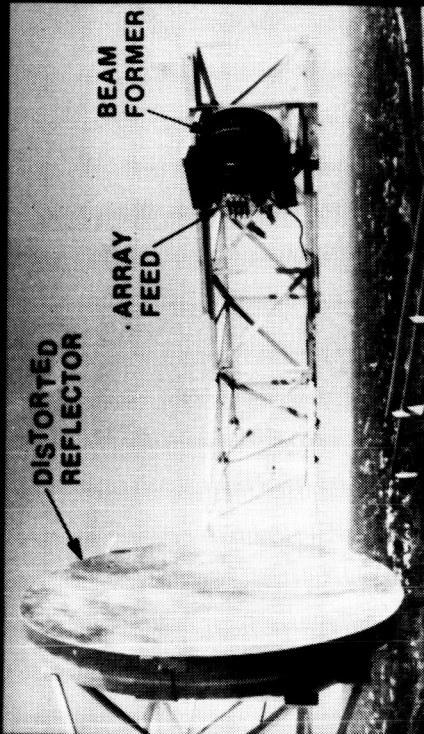
The fabricated reflector and the array feed are shown in the upper left corner. The array consists of 19 cigar elements with an analog phase shifter and variable attenuator behind each element. The preliminary results of this experiment are shown in the lower left corner. At the present time the experiment has been manually implemented by properly adjusting each element's amplitude and phase. From the results, it is observed that the array feed has improved the reflector performance considerably both in terms of improved gain and pattern characteristics that agree well with the computer predicted performance.

The results of this experimental study should be expanded to test the applicability of an adaptive scheme to directly identify the required excitation coefficients of the compensating feed array without actually measuring the reflector surface. This, we believe, is an essential step if such a compensating algorithm is going to be utilized in future large space antennas. This may also introduce a new direction for the design concept of large antennas by relaxing surface accuracy requirements.

TECHNICAL CONTACT: Dr. Yahya Rahmat-Samii, JPL (818) 354-5714

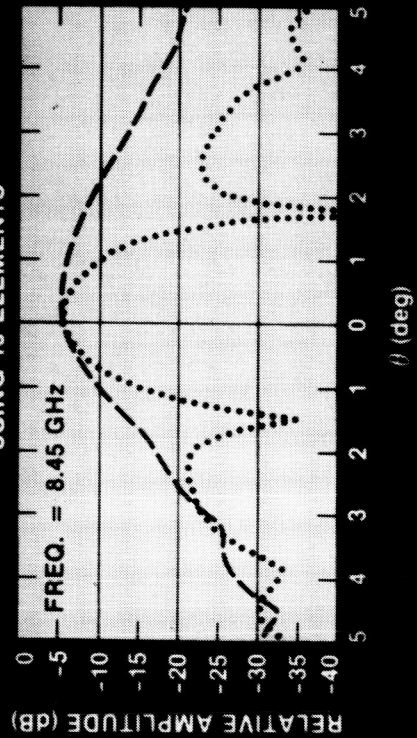
JPL REFLECTOR DISTORTION COMPENSATION BY ARRAY FEEDS

EXPERIMENTAL SETUP



VERIFICATION

--- MEASURED ORIGINAL PATTERN
 MEASURED COMPENSATED USING 19 ELEMENTS



APPLICATIONS

- TO IMPROVE PERFORMANCE OF LARGE SPACE OR GROUND REFLECTOR ANTENNAS
- TO PROVIDE A NEW WAY TO RELAX SURFACE REQUIREMENTS
- TO BE UTILIZED ADAPTIVELY FOR ONBOARD COMPENSATION

Integrated Optical Communication Test Bench

Optical communications components (lasers, modulators, detectors, etc.) are usually developed as individual items; their performance requirements are specified and measured in isolation. When placed in the context of a communication application, however, interactions between adjacent components can alter the elements', and, hence, the system's performance. Examples include: reflections off of focusing optics, which can feedback to alter the operation of a laser; or insufficient isolation between transmit and receive optics, which can alter communication, acquisition, or tracking performance. This activity has created an integrated technology test bench for the evaluation of optical communication components in a realistic functional setting, and for testing different transceiver configurations.

With optical communications techniques, spacecraft transmitting apertures of 10 to 40 cm will be adequate for Galileo-class or better service. The small antenna size means that the communications system need only occupy a small portion of the spacecraft, as opposed to being a main structural member. This factor relaxes launch envelope constraints and increases launch vehicle options. For Galileo-class service, about an order of magnitude less radiated power is required for communication at optical frequencies than at radio frequencies. The excellent angular resolution possible with optical spatial tracking techniques (presently 10 nrad from Earth and the 100 prad projected from Earth orbit) offers potential improvement in tracking precision over the precision possible with RF interferometric techniques, while eliminating the need for multiple stations or long observation times. This improved tracking capability, together with future spacecraft flybys or encounters, will also permit improvement in the knowledge of solar system ephemerides. Taken together, these capabilities indicate the need to develop a means to test the overall functionality of, and the constraints on, an optical communications transceiver that incorporates combinations of these technologies. Such a transceiver package has been proposed as an experiment on the Cassini mission.

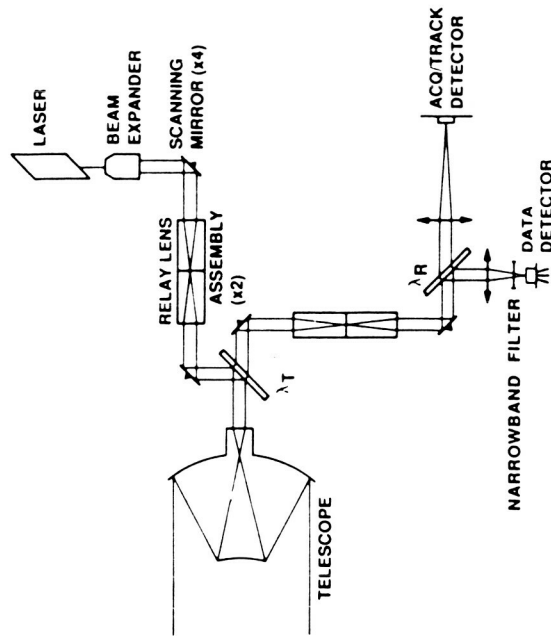
During the past year a number of refinements were made to the test bench. The optics for performing independent transmit-beam point-ahead were designed and incorporated into the test bench. Computer control of the transmit-beam pointing was implemented. A near real-time display of the digitized full-frame acquisition and tracking detector image was implemented using computer-stored data and fixed-pattern noise subtraction: the first step in the development and testing of advanced acquisition and tracking algorithms. Also, an optical system to simulate planetary distances on a laboratory bench-top was constructed.

Currently, the test bench is being used to develop and test acquisition algorithms, working toward 1/10 pixel pointing and tracking resolution.

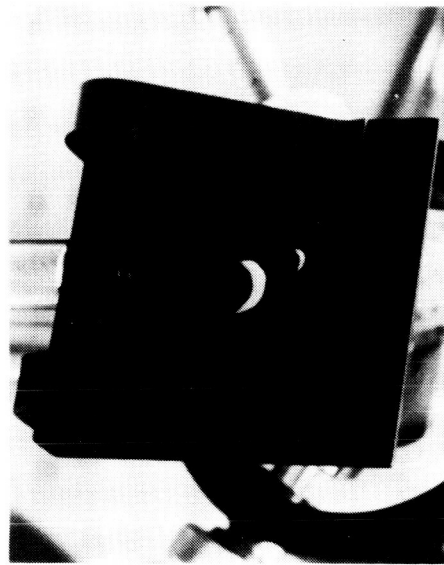
TECHNICAL CONTACT: James R. Lesh, JPL (818) 354-2766

JPL INTEGRATED OPTICAL COMMUNICATION TEST BENCH

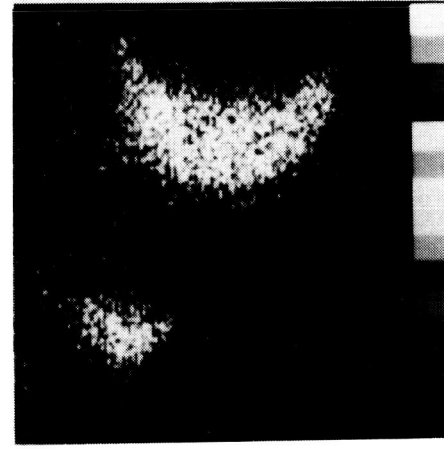
A REAL-TIME DISPLAY OF THE DIGITIZED FULL-FRAME ACQUISITION AND TRACKING IMAGE HAS BEEN IMPLEMENTED



INTEGRATED OPTICAL COMMUNICATION TEST BENCH OPTICAL ARRANGEMENT



SIMULATED PLANETARY TARGET



DIGITIZED ACQ/TRACK IMAGE OF PLANETARY TARGET

High Efficiency Lasers

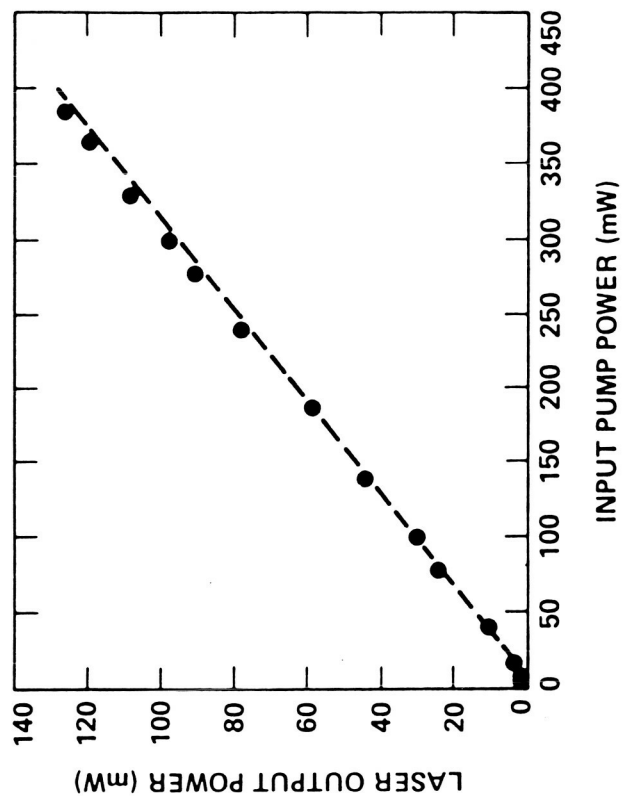
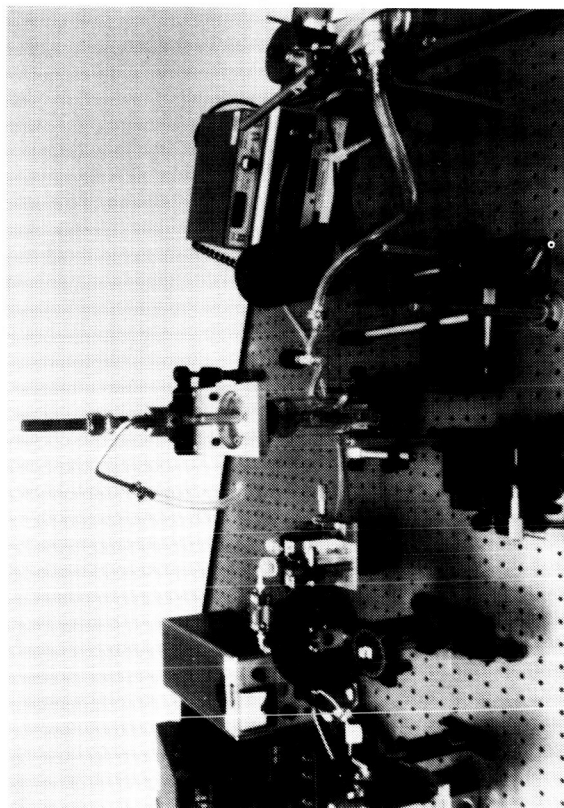
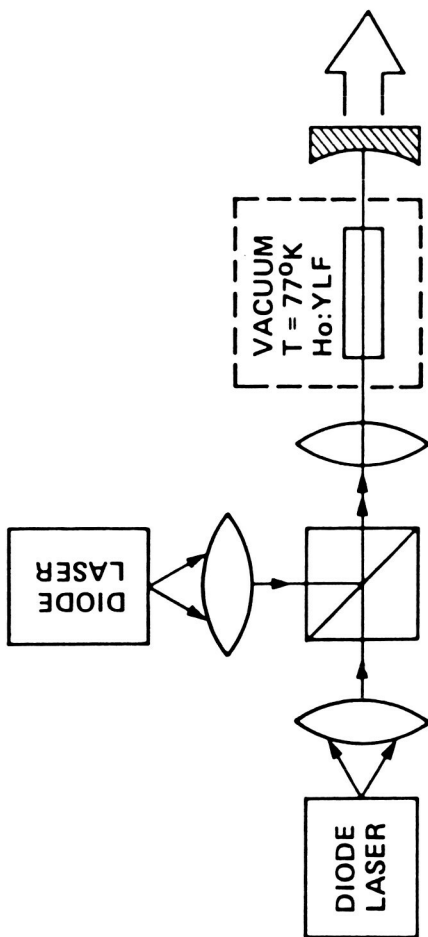
A class of highly efficient lasers is the solid state lasers (such as Nd:YAG), which are optically pumped with a diode laser. Semiconductor lasers are highly efficient, compact, and lightweight. When coupled with a properly selected laser crystal, the result is a second efficient laser with output wavelength of interest and capable of producing high peak power pulses.

In many space applications involving remote sensing, laser radar, or deep space optical communications, efficient laser sources capable of providing high pulse energies are desired or required. To achieve laser pulse energies at the millijoule or higher levels, needed in many situations, either semiconductor laser pumping sources with extremely high peak power capabilities or lasing media (crystals) with much longer fluorescence lifetime will be required. Semiconductor lasers, although maturing rapidly, seem to be inherently limited in peak power performance in all but extremely low duty cycle conditions.

Lasing was recently demonstrated at JPL in holmium doped yttrium lithium fluoride (Ho:YLF) crystal when pumped by a semiconductor laser array. Five-fold improvement in the output power has been achieved when combined output of two diode array pump lasers are used in conjunction with an optimized output coupler mirror. Continuous-wave output of 130 mW at 2.06 μm has been achieved utilizing a crystal cooled to 77 K. Room temperature operation of the laser with a new custom-grown Ho:YLF crystal is being investigated.

TECHNICAL CONTACT: James R. Lesh, JPL (818) 354-2766

**A DIODE-LASER-ARRAY PUMPED
Ho:YLF LASER WITH OUTPUT
WAVELENGTH OF 2 μm AND 125
mW OF POWER WAS OPERATED
FOR THE FIRST TIME**



Space Laser

Efficient, alignment-free, lightweight, compact, diode-laser pumped Nd:YAG lasers are prime candidates as deep space optical communication sources.

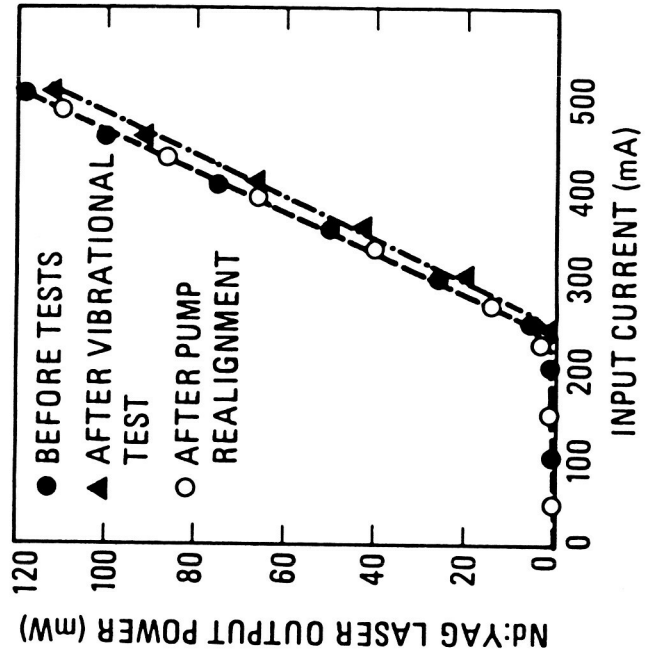
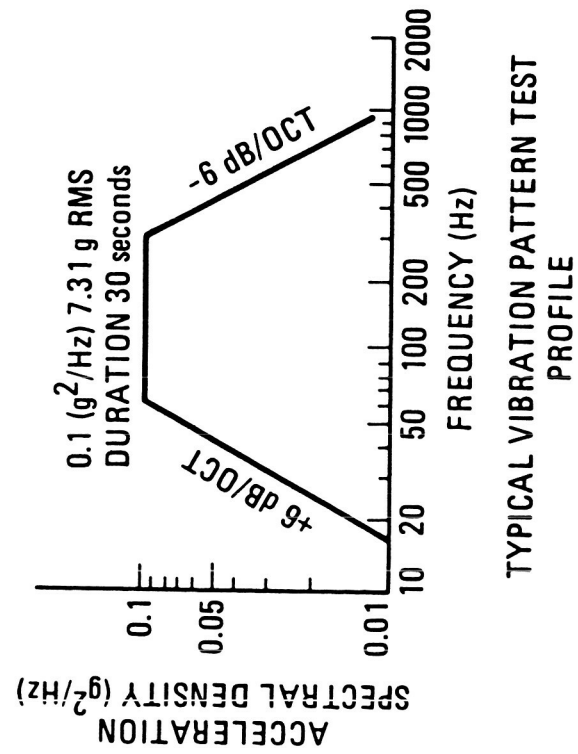
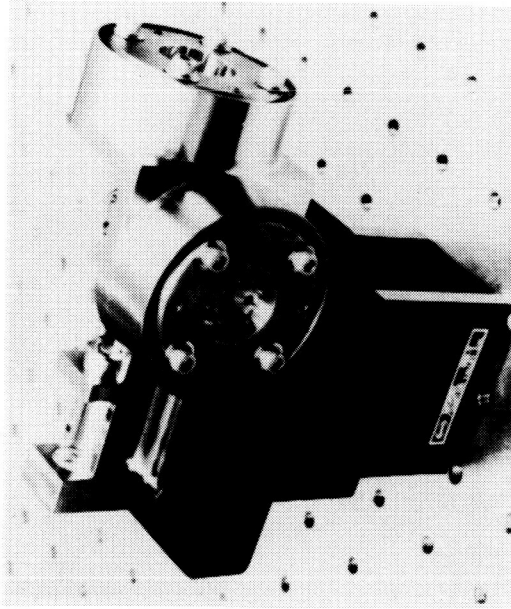
The technology of laser sources for free space optical communications is not sufficiently well developed and space qualified. Single laser diodes are power limited, diode laser arrays have unpredictable far field patterns, and conventional solid state lasers are power inefficient. This work concentrated on laser sources which yield high overall power efficiency, high peak and average power levels, and versatile modulation control.

An alignment-free and compact diode-laser-pumped Nd:YAG laser has been designed, built, and tested under launch thermal/vibrational conditions. Upon vibrational testing, output became multimode with 9% decrease in power. Readjustment of one of the pump diode laser modules restored full 120 mW output power. No damage was observed to the pump diode lasers and the passive optical elements. The Nd:YAG laser optical cavity remained intact. Findings from this laser design are being incorporated into a new laser module design.

TECHNICAL CONTACT: James R. Lesh, JPL (818) 354-2766

SPACE LASER

ENVIRONMENTAL TESTS WERE
PERFORMED ON THE POLARIZATION-
COUPLED PUMPED Nd:YAG LASER



Free Space Laser Communications Transmitters and Receivers

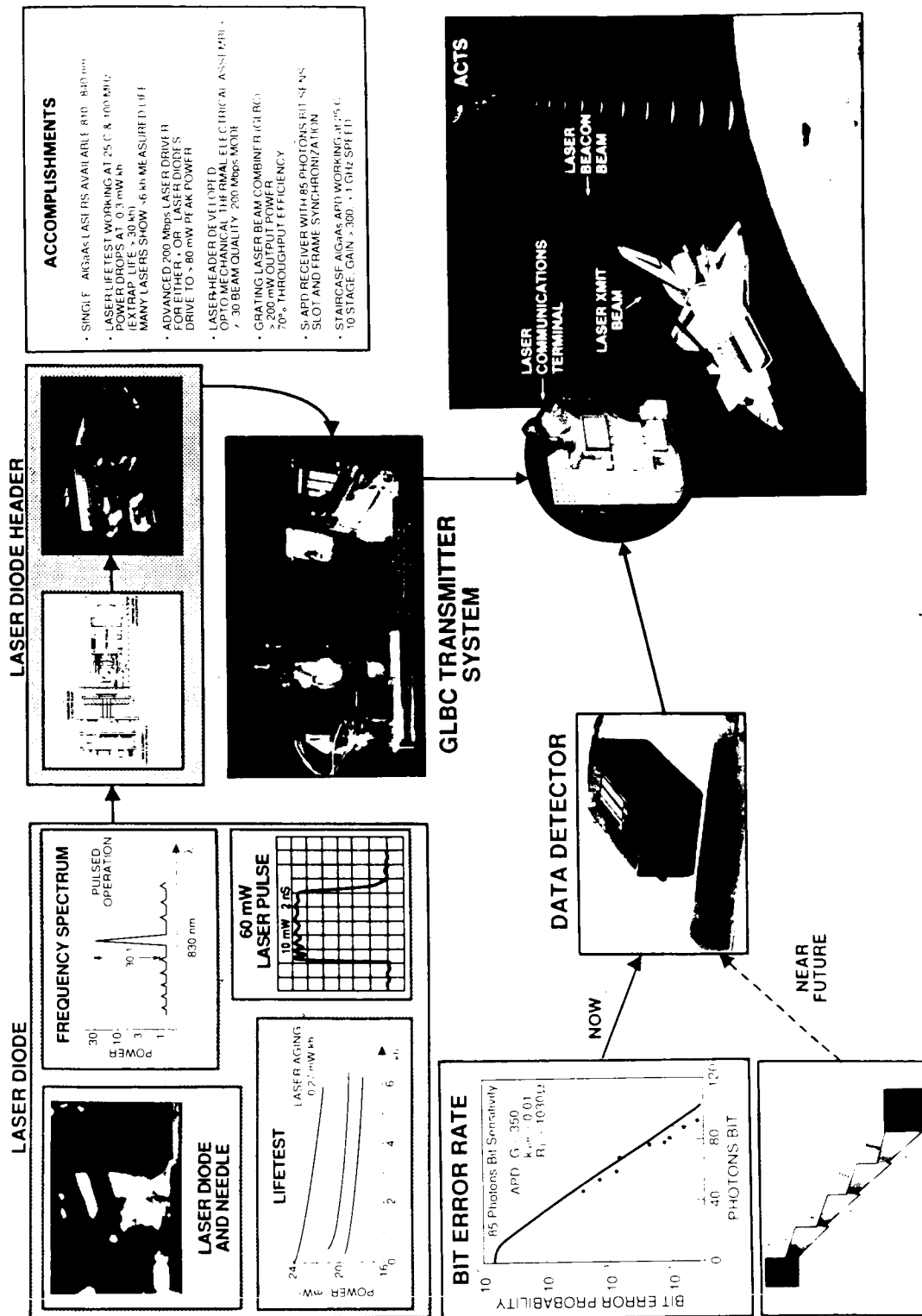
Laser systems are attractive for satellite communications systems because they are small, all solid state, and are capable of carrying data rates in excess of 200 Mbps. NASA is developing laser systems that transmit data between satellites by directly modulating the output powers of semiconductor lasers with injected current. Although powers in excess of 100 mW are required to carry NASA data rates, the best commercially available semiconductor lasers are limited to powers less than 40 mW. Furthermore, single frequency operation and long life has not been demonstrated for lasers operating under the conditions that are required for space systems.

Goddard Space Flight Center is developing the high-power diffraction-limited AlGaAs transmitter systems required for the laser transmitters. Recent work has shown considerable progress toward developing long-lived transmitters capable of several hundred Mbps. Significant accomplishments during FY88 were as follows: 1) Single wavelength AlGaAs lasers are now available from 810 to 840 nm. These are required for transmitter laser beam combiners. 2) A laser lifetest is operational that tests lasers at 25°C with 100 MHz modulation. Results show laser power drops 0.3 mW/kh, that leads to extrapolated lifetimes of greater than 30 kh. Several laser types show >6 kh measured lifetime with little change. 3) A 200 Mbps laser driver was developed and modulates either positive or negative polarity laser diodes. Its drive level permits 80 mW peak powers and exceeds the state of the art. 4) A laser diode heater has been developed. It combines the optical, mechanical, thermal, and electrical functions of the transmitters into a single assembly. The present design maintains 1/30 beam quality and allows 200 Mbps modulation speeds. 5) A Grating Laser Beam Combiner (GLBC) has been supported. This parallel incoherent combining approach will emit >200 mW output power and has 70% throughput efficiency. The approach can be scaled and future versions should have greater output powers.

High-sensitivity detectors significantly enhance communications systems performance and permit higher data rates and/or lower transmitter powers. Our work in previous years developed silicon avalanche photodiode (Si APD) receivers with the highest sensitivity yet reported at medium (25 Mbps) and high (300 Mbps) data rates. Significant accomplishments were made during FY88. An Si APD receiver with slot and frame synchronization was demonstrated 85 photons/bit sensitivity. A developmental staircase APD grown in AlGaAs was successfully demonstrated and tested at 25°C. The Bell Laboratories' device had 10 stages, showed a gain in excess of 300, had greater than 1 GHz bandwidth, and a response uniformity of better than 10%. Its successful demonstration is a significant milestone in developing a new type of extremely sensitive optical detector in the near infrared that will benefit many NASA programs.

TECHNICAL CONTACT: James B. Abshire, GSFC (301) 286-8948

FREE SPACE LASER COMMUNICATIONS TRANSMITTERS AND RECEIVERS



Ka-Band MMIC Power Amplifier

Aimed at support of deep space and interplanetary communications, LeRC has undertaken the development of a set of Ka-band (32.5 GHz) monolithic microwave integrated circuit (MMIC) power amplifiers. Such a development, with sufficient power and efficiency, would constitute enabling technology for the implementation of electronically steerable phased array antennas at this frequency.

Texas Instruments has been under contract for this purpose for approximately 36 months. In this time, utilizing both conventional mesfet technology and the more advanced pseudomorphic (InGaAs) structures. TI has produced devices with power densities of 0.6 to 0.8 watts/mm, and efficiencies of over 40% at 32 GHz.

A set of 12 matched 100 mW amplifiers has been delivered to JPL for evaluation in a breadboard demonstration of a phased array (1X8) antenna.

Possible applications include: CRAF Ka-Band experiment, phased array antenna feed for CASSINI mission; phased array for MARS ROVER sample return mission; and commercial phased arrays for space communications.

TECHNICAL CONTACT: E. Haugland, LeRC (216) 433-3516

Ka BAND MMIC POWER AMPLIFIER

GaAs Cap Layer 400 Å	
$\text{Al}_{0.23}\text{Ga}_{0.77}\text{As}$	$2 \times 10^{18} \text{ 500 Å}$
$\text{In}_{0.15}\text{Ga}_{0.85}\text{As}$	$2 \times 10^{18} \text{ 100 Å}$
GaAs	$2 \times 10^{18} \text{ 80 Å}$
GaAs Buffer 1 μm	

Substrate

DOUBLE PSEUDOMORPHIC DOPED DEVICE STRUCTURE

BENEFITS

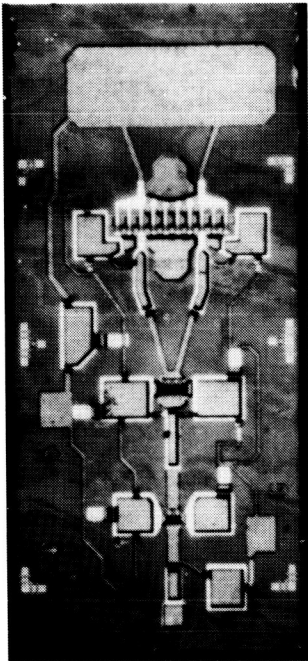
- HIGH EFFICIENCY MMIC AMPLIFIERS

32.5 GHz 0.1 watt 35% EFFICIENCY

- BEST DEVICE RESULTS AT 35 GHz

GaAs	0.6 watt/mm	41% EFFICIENCY
AlGaAs/InGaAs/GaAs (PSEUDOMORPHIC)	0.8 watt/mm	42% EFFICIENCY

- TWELVE MATCHED 100 mwatt AMPLIFIERS INSTALLED
IN JPL DEMO



32.5 GHz 3 STAGE MMIC AMPLIFIER
(2.6 mm x 1.2 mm)

Ku/K Band Monolithic Microwave Integrated Circuit (MMIC) Power Amplifiers

In response to the requirements of the space station multiple access communications system, NASA LeRC has undertaken the development of two sets of power amplifier chips. The first set, operating at 13 - 15 GHz, consists of a 2-W fixed power amplifier, a 2-W variable power amplifier, and a 4-W high power amplifier. This set of modules has been under development at Texas Instruments under LeRC management for approximately 22 months. The performance goals of the contract represent record achievements in power and efficiency. To date, TI has achieved 0.9 W of power output at 28% efficiency in a monolithic four-stage variable power amplifier. Over 55% efficiency has been obtained for a discrete FET at this frequency. Preliminary modules have been delivered to JSC for subsystem and environmental evaluation.

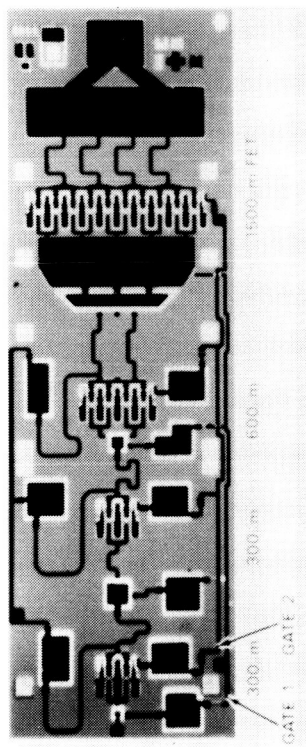
In a contract to be initiated in FY89, a set of Ka-band (21-23 GHz) chips will be developed in response to an anticipated change in frequency for the space station communication system. To date, LeRC personnel have prepared a Statement-of-Work scheduled for release in mid-August. Goals of the contract include a 4-W monolithic amplifier with 30% efficiency, and a hybrid 6-W amplifier with 25% efficiency.

TECHNICAL CONTACT: Regis Leonard, LeRC (216) 433-3500

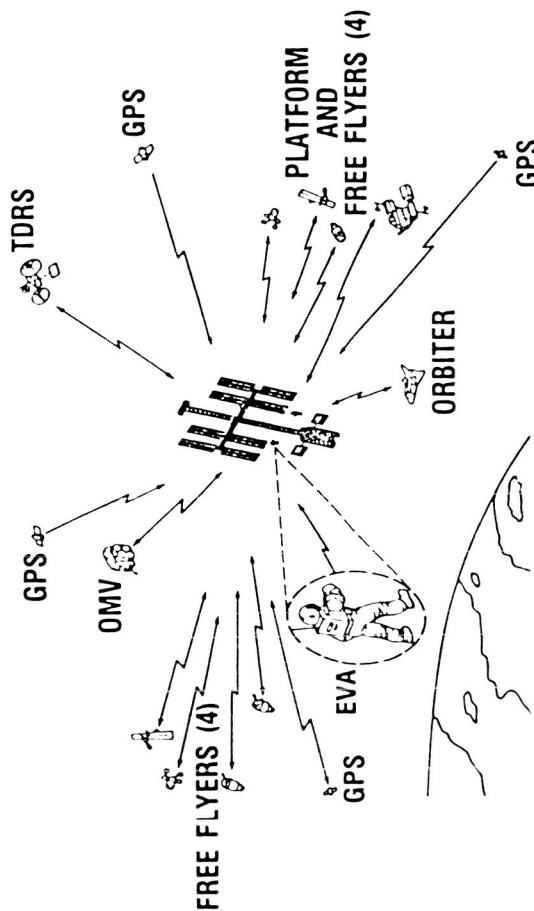
Ku/K BAND MMIC POWER AMPLIFIERS

SPACE STATION COMMUNICATIONS
AND TRACKING LINKS

Ku-BAND VARIABLE POWER AMPLIFIER



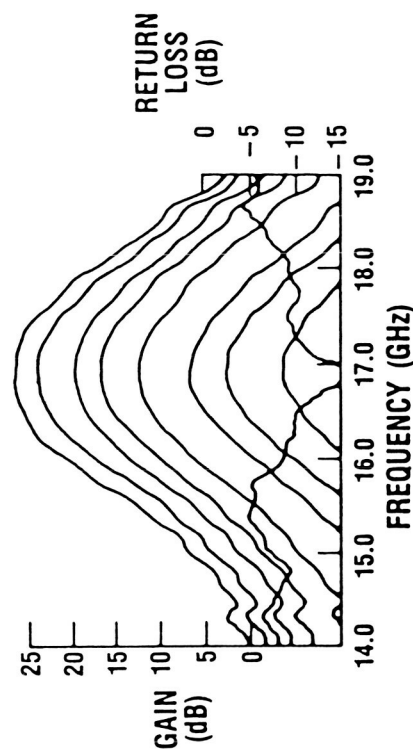
CHIP SIZE: 254 mils x 83 mils



MAJOR PERFORMANCE GOALS

Ku-BAND POWER	(13-15 GHz) EFFICIENCY	K-BAND POWER	(21-23 GHz) EFFICIENCY
VPA*	1W	2W	30%
MPA	1W	2W	30%
HPA	4W	6W	25%

*ACHIEVED 912 mW OUTPUT POWER WITH 28% POWER ADDED
EFFICIENCY



Miniature Electron Beam Devices

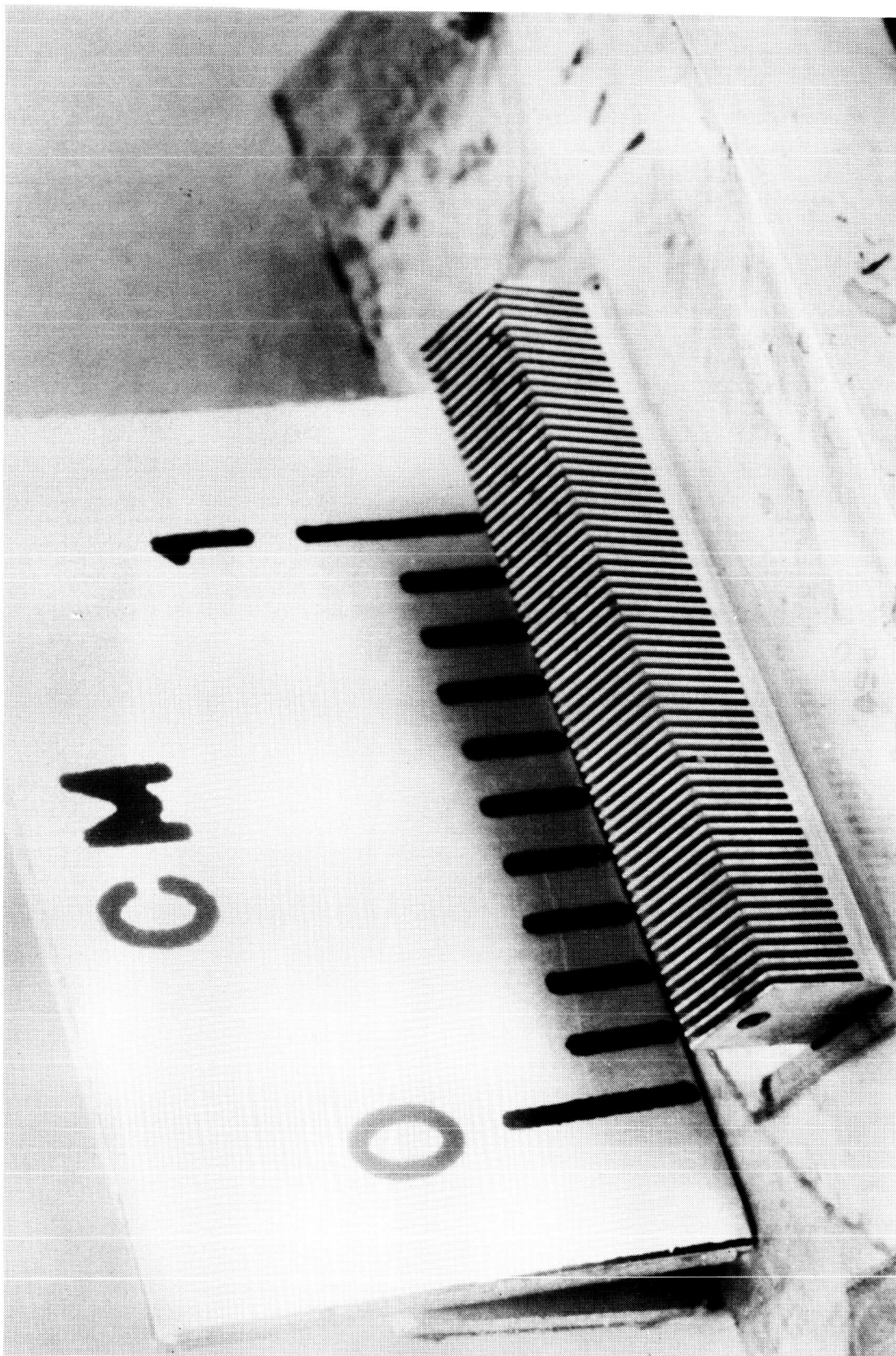
While tube technology has achieved an extraordinary record of success in increasing the power available from a single device at a particular frequency, little attention has been devoted to devices with power outputs on the order of one to five watts for which there is likely to be an increasing demand for NASA, commercial, and military applications. Typically, when electron beam devices in this power range are built at all, they are built as derated versions of high power tubes. Therefore, they are virtually the same size and weight as higher power tubes. Moreover, they are far less efficient since they require nearly the same cathode heater power.

Based on work performed over the last several years in-house and by NASA contractors, a new class of very small, efficient, low power electron beam devices is being developed at LeRC using the microfabrication technology originated by the semiconductor industry. The immediate goal of this program is to develop a small, 1.5 W, 30 GHz traveling wave tube with 25 dB gain and an efficiency of 50%.

The slow wave circuit chosen for this device is a modified version of the linear magnetron circuit. A full-size model of the circuit, fabricated at LeRC is shown in the attached figure. Computations have been made of the dispersion relations and circuit interaction impedance and these have been verified experimentally by cold testing, using a scaled circuit at 1.0 GHz. In order to achieve the highest possible efficiency, an electron gun with a field emission cathode ultimately will be needed, but for the first demonstration of the device good efficiency is expected to be obtained using an electron gun with a low power oxide cathode. A multistage depressed collector will be needed to achieve the desired levels of device efficiency, but a single stage collector will be used in the first device. Computer-aided estimates of the electron beam transmission with rf drive indicate that an external magnetic field will not be needed to achieve the desired rf power levels.

TECHNICAL CONTACT: Thomas Wallet, LeRC (216) 433-3673

MINIATURE TRAVELING WAVE TUBE



High Efficiency TWT with Dynamic Velocity Taper

Based on the expected success of current research on Traveling Wave Tube (TWT) efficiency enhancement it is reasonable to predict the development of a new class of very high efficiency amplifiers for future space communications applications. A contract has been let to Watkins-Johnson to fabricate, test, and deliver six TWTs that will serve as experiment verification of LeRC computer predictions for novel dynamic velocity taper (DVT) circuits as test vehicles for multistage depressed collectors (MDCs) with electrodes designed to minimize secondary electron emission. These tubes are designed for 8.4 GHz, the frequency currently used in the deep space network, and the 20 W power output was chosen in consultation with JPL.

Three of the TWTs feature an output helix section DVT designed for maximum gain while the DVT for the other three is designed for minimum signal distortion and phase shift. Four of the six sets of MDC electrodes are to be treated at Lewis with in-house developed ion-texturing processes to enhance MDC efficiency by reducing surface secondary electron emission. The DVT and MDC electrical designs were performed at Lewis and supplied to the contractor for fabrication. Objectives of the program include achieving overall TWT efficiency of at least 55%, saturated gain of 48 dB, and a design lifetime of 10 years. Tests at Watkins-Johnson with the first TWTs (with underpressed collectors) indicate good agreement between predicted and measured RF efficiencies with as high as 30% improvement in RF efficiency over conventional helix designs.

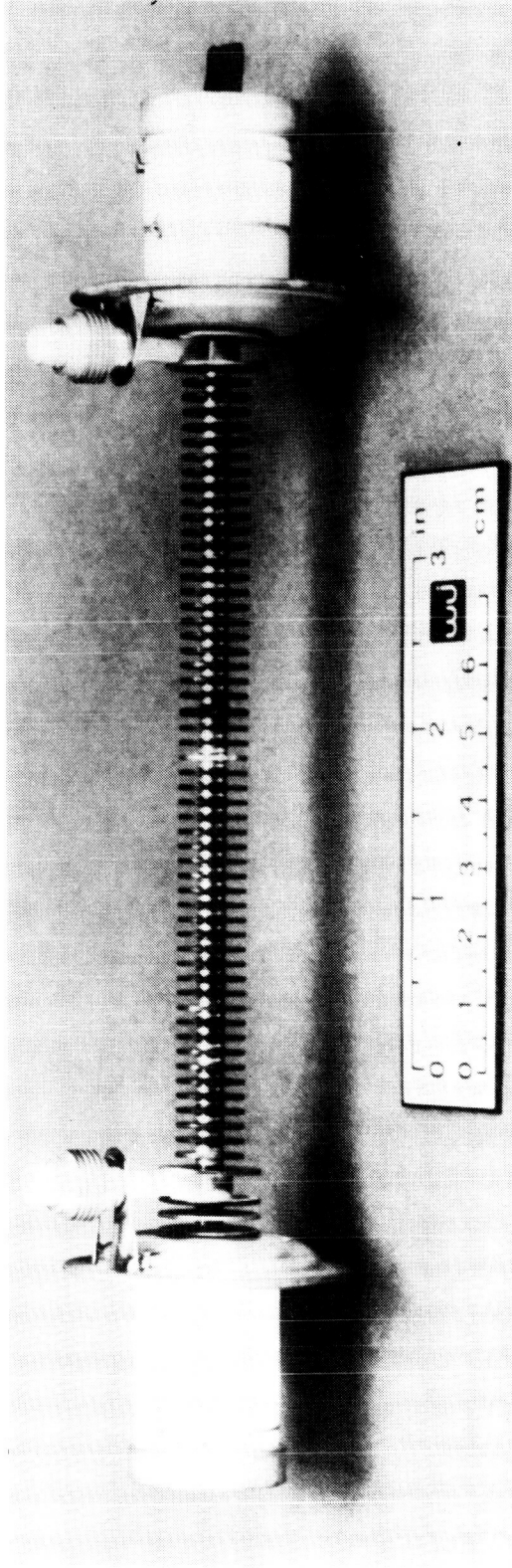
Two complete sets of MDC modules (eight pieces in all) with high-purity isotropic graphite electrodes have been ion-textured at Lewis and returned to Watkins-Johnson for assembly and mating with a TWT for testing. Two additional sets of MDC modules with copper electrodes are now being similarly surface-treated at Lewis and will shortly be returned to the contractor as well.

By coincidence, Watkins-Johnson is also under contract with GE/RCA to build the 44 W 8-4 GHz TWTs for the JPL Mars Observer Mission. When W-J was unable to meet the mission requirements for TWT efficiency, they requested LeRC assistance in the design of a DVT circuit. The LeRC design permitted W-J to exceed specifications, providing direct technology transfer from the OAST research program to this OSSA mission.

Consultations are continuing between LeRC and JPL regarding application of this efficiency enhancement technology to 32 GHz transmitters for the Cassini and Mars Rover Missions. A draft Statement-of-Work for a TWT amplifier for use on Cassini is presently under review by JPL.

TECHNICAL CONTACT: Arthur N. Curren, LeRC (216) 433-3519

HIGH EFFICIENCY TWT WITH DYNAMIC VELOCITY TAPER



ACCOMPLISHMENTS

- EXPERIMENTAL VERIFICATION AT 8.4 GHz BY WATKINS-JOHNSON OF LeRC COMPUTATIONAL PROGRAM
- IMPROVEMENTS IN POWER OUTPUT OF 30% OVER CONVENTIONAL CIRCUITS
- NOVEL SECONDARY ELECTRON SUPPRESSION EMPLOYED IN COLLECTOR
- LeRC TAPER DESIGN USED ON MARS OBSERVER TWT

IMPACT

- VERY HIGH EFFICIENCY AMPLIFIER TECHNOLOGY AVAILABLE TO CASSINI AND MARS ROVER MISSIONS

RC894

Low Distortion High Power 29 GHz TWT

High data-rate ground terminals for future space communications require high-power traveling wave tubes (TWT) operating in the neighborhood of 30 GHz. At this frequency, high power can best be achieved by using a coupled cavity TWT, but these devices inherently introduce greater signal distortion and are more costly than the more common helical TWTs used at lower power and lower frequency.

The primary purpose of this research is to experimentally study methods of reducing signal distortion and cost in coupled-cavity TWTs with power and frequency characteristics compatible with 30 GHz ground station transmitters. This experimental program is conducted on contract with Hughes Electron Dynamics Division in parallel with a LeRC in-house computational effort.

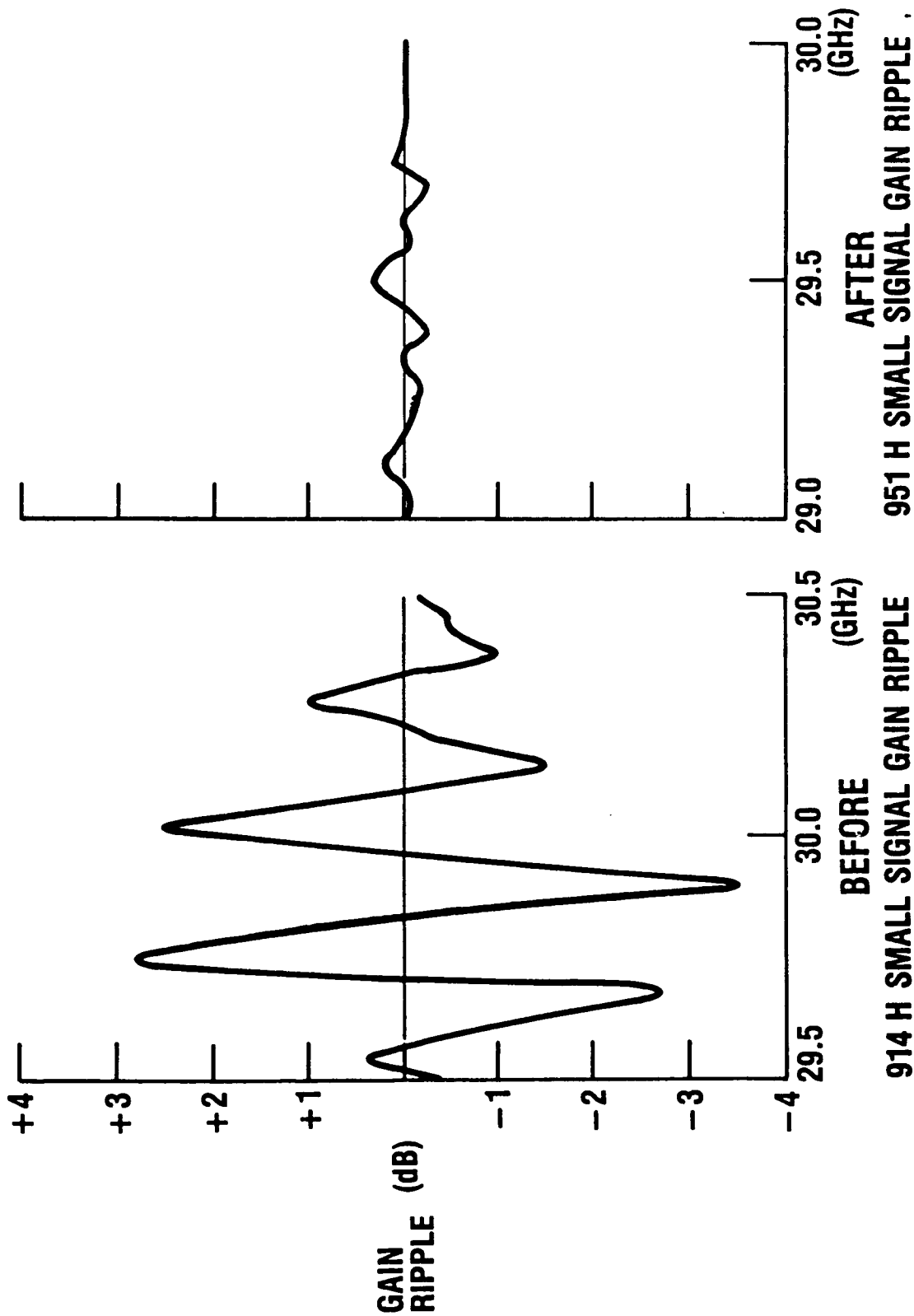
Two 29 GHz, 400 W coupled-cavity traveling-wave tubes with ferruleless cavities have been built and tested under the research and development contract with Hughes. Measurements made by Hughes and computations made at LeRC both indicate that the most important factor in reducing the small signal gain ripple, which causes signal distortion, is the design of a good output match. Excellent low-reflection matches were obtained in both TWTs. This led the way to outstanding low distortion characteristics. The small signal gain ripple for both TWTs was less than 0.5 dB, which is a considerable improvement over any known high-power TWT at this frequency. The small signal gain ripple over the 1 GHz bandwidth for the second TWT is shown in the figure compared to the ripple for a typical high-power coupled cavity TWT (Hughes model 914H) at a similar frequency. The improvement in reducing small signal gain ripple from 6 dB to 0.4 dB is quite evident.

The third TWT has just been fabricated and is almost ready for testing. It has a different design in that the cavities are slightly longer. Theoretically this will provide for more destructive interference of the backward wave and thus decrease the feedback responsible for distortion. The fourth and fifth TWTs will employ NASA-designed velocity tapers to optimize efficiency.

The technology developed on this program is generally applicable to all mm-wave coupled cavity TWTs and will enable a new class of high data-rate transmitters for space communications.

TECHNICAL CONTACT: Jeff Wilson, LeRC (216) 433-3513

HIGH POWER TWT DISTORTION REDUCTION



30 to 70 GHz MMIC Transmitter Technology

In order to demonstrate the usefulness of the InGaAs pseudomorphic structure, previously developed under LeRC grant at the University of Illinois, and to expedite its insertion into NASA programs, LeRC has awarded a contract for the development of 4 chips based on that technology.

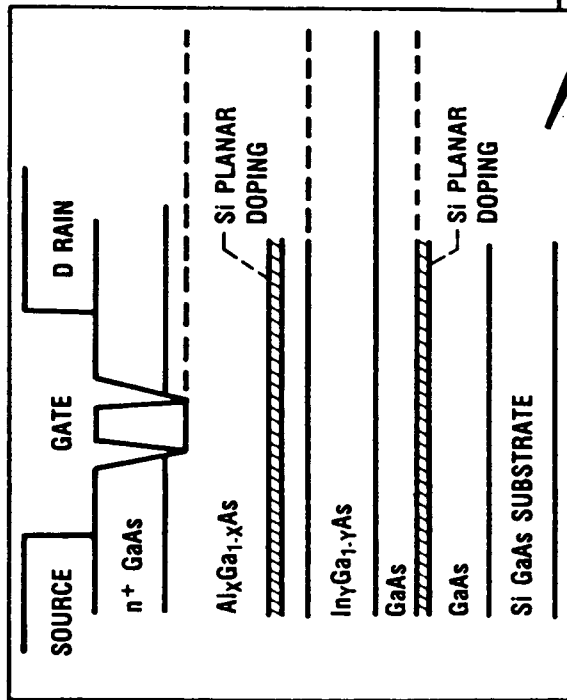
The chips consist of monolithic phase shifters at 32 and 60 GHz and variable power amplifiers at 32 and 60 GHz. The effort, awarded to Hughes Aircraft in May 1988, will attempt to produce monolithic amplifiers with 15 dB of gain, 150 mW of power, and 40% efficiency at 32 GHz; 15 dB of gain, 100 mW of power and 30% efficiency at 60 GHz, all of which would represent record achievements at these frequencies. The contract has a 36-month period of performance.

The 32 GHz chips are aimed at insertion in deep space communications, the 60 GHz chips are at use in intersatellite communications.

TECHNICAL CONTACT: K. Bhasin, LeRC (216) 433-3676

30 TO 70 GHz MMIC TRANSMITTER TECHNOLOGY

InGaAs/GaAs PSEUDOMORPHIC HEMT STRUCTURE



CONTRACT GOALS

CONTROLLED GAIN AMPLIFIER

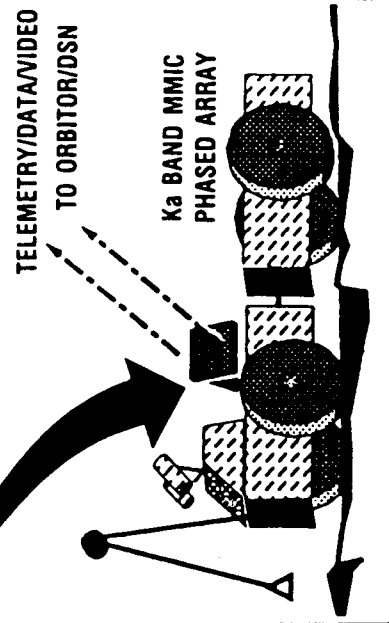
• RF POWER	32.5 GHz	60 GHz
• RF GAIN	150 mW	100 mW
• EFFICIENCY	15 dB	15 dB
	40%	30%

0-360° PHASE SHIFTER

• INSERTION LOSS	≤ 6 dB	≤ 8 dB
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CONTRACT GRANTED TO HUGHES AIRCRAFT CO./MAY 1988

MARS ROVER



Optical/MMIC Control Interface Development

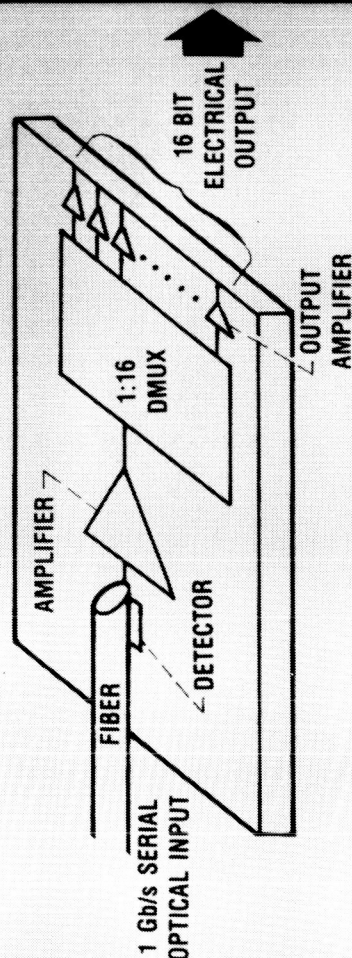
Interconnect circuitry for feed and control of large phased array antennas appears to be a significant problem in terms of weight, volume and topological complexity. One possible solution to this problem would employ lightweight, low-volume optical fibers to supply control data to MMIC modules (phase shifters, variable gain amplifiers) used in the array. To demonstrate the feasibility of such a system, LeRC has developed a GaAs module that serves as an interface between an optical fiber carrying a high speed (1 GBPS) digital data stream and an MMIC module.

Under contract for the last 30 months, Honeywell has produced a chip consisting of optical detector, low noise amplifier, demultiplexer, and drivers for 16 parallel TTL outputs. The technology used in the chip is compatible with integration with the RF portions of the MMIC module to produce a fully monolithic unit.

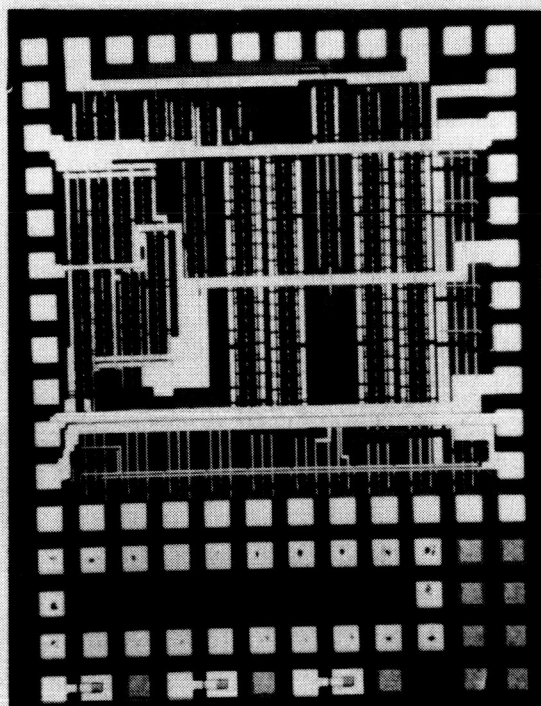
All critical subassemblies have been fabricated and successfully tested. The first submodules will be delivered in the first quarter of FY89; the monolithic module during the second quarter of FY89.

TECHNICAL CONTACT: K. Bhasin, LeRC (216) 433-3676

OPTICAL/MMIC CONTROL INTERFACE DEVELOPMENT



OPTICAL IC LAYOUT

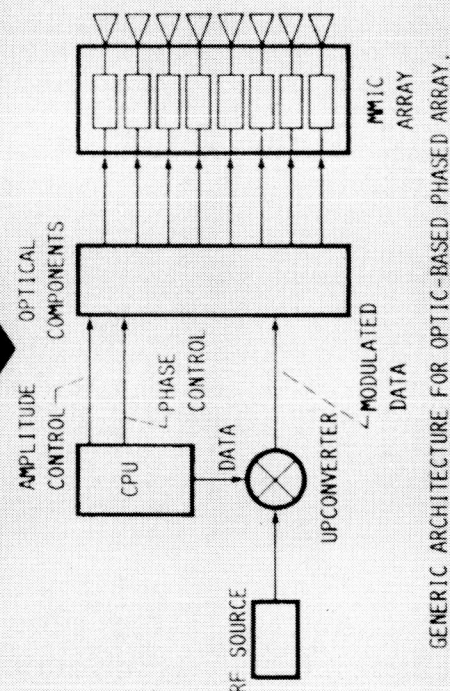


GaAs MONOLITHIC INTEGRATED CONTROL CIRCUIT

PERFORMANCE STATUS

- DETECTOR RESPONSE > 1.35 GHz
- LOW POWER ~ 277 mW (WITHOUT TTL OUTPUT)
- PROVIDES 16 OUTPUTS FOR SINGLE INPUT
- DETECTOR SENSITIVITY ~ 0.35 A/W

CD-88-35404



GENERIC ARCHITECTURE FOR OPTIC-BASED PHASED ARRAY.

Active Feed Array Compensation for Reflector Antenna Surface Distortion

Satellite communications and future NASA scientific missions will utilize large reflector antennas with stringent gain and sidelobe level requirements. The performance accuracy of these reflectors can be degraded due to surface distortions caused mainly by thermal effects from solar radiation. Adaptive array feed compensation can be used to maintain the design antenna performance independent of thermal effects on the reflector surface.

Adaptive array feed compensation is feasible due to recent advances in monolithic microwave integrated circuits (MMIC) array technology. MMIC array provides independent control of amplitude and phase for each of many radiating elements in the feed array. It is the direct control of the array excitations that account for the compensation of thermal effects on the radiation performance of the antenna. Existing feed array compensating techniques only compensate for gain degradations, leaving the far field antenna pattern with very high sidelobes. The technique developed at Lewis compensate for sidelobe as well as gain degradations due to thermal effects. The concept of conjugate field matching (CFM) is utilized to determine the complex excitation coefficients of the feed array.

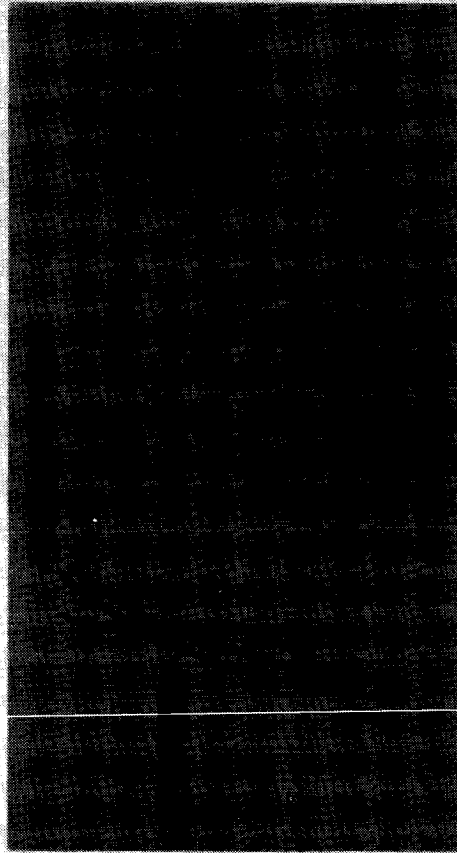
A generalized 3-D computer program has been developed that automatically generates the compensated feed excitation coefficients for a given distortion surface profile. The algorithm is capable of producing the compensated far field pattern with gain and sidelobe control. The computer code has been checked using simulated distortion profiles superimposed on an offset reflector geometry. Results indicate that the gain can be compensated to within 1 - 2 dB and sidelobe levels to within 2 - 5 dB of the undistorted antenna pattern if a sufficient number of array elements are available. The example shown indicates the degree of compensation achievable with 37 elements for a 30 GHz, 150 λ reflector with a peak distortion of 1 λ .

An experimental effort is being planned for verifying the above algorithm with the use of a distorted reflector and a MMIC feed array.

A detailed description of the approach is described in: "Case study of active array feed compensation with sidelobe control for reflector surface distortion", R. Acosta, 1988 IEEE AP-S International Symposium Vol. II, Syracuse, NY.; and "Active feed array compensation for reflector antenna surface distortion", R. Acosta, Akron University, Doctoral Dissertation, May 1988.

TECHNICAL CONTACT: R. Acosta, LeRC (216) 433-3491

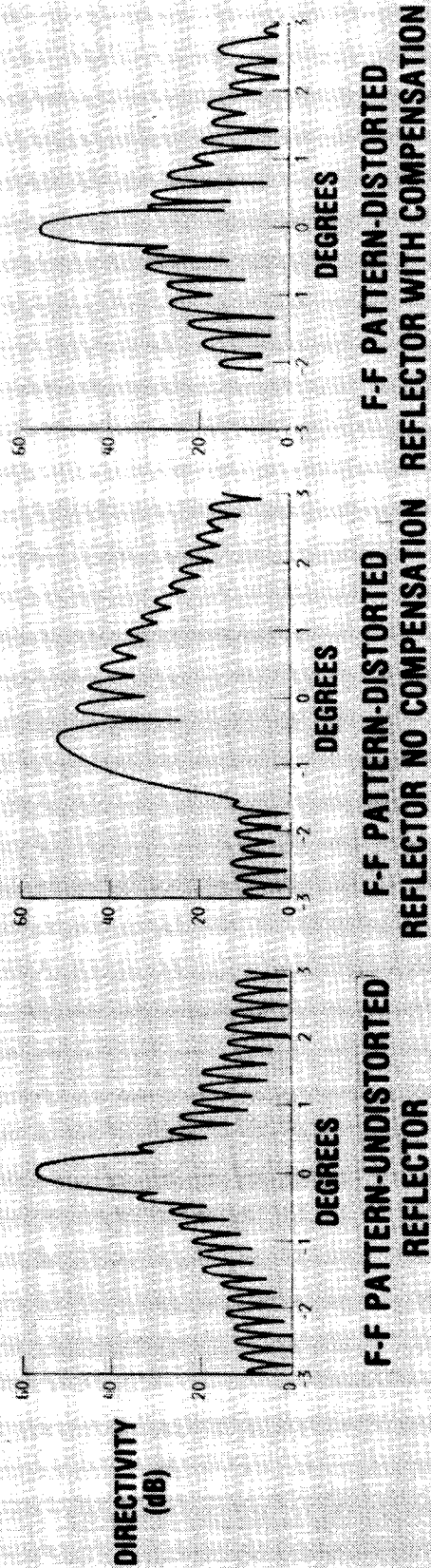
ACTIVE FEED ARRAY COMPENSATION FOR REFLECTOR ANTENNA SURFACE DISTORTION



FEATURES

- DIRECT SIDELobe LEVEL CONTROL
- GAIN CONTROL
- EASE OF IMPLEMENTATION
- ADAPTIVE (REAL TIME)

FREQUENCY = 30 GHz, REFLECTOR DIA = 150 λ , PEAK DISTORTION = 1λ , ARRAY
SIZE = 37 ELEMENTS



Phased Array Semiconductor Laser

The objective of this research was to develop and demonstrate a high-power, single spatial mode, phased array laser with high-speed modulation capability for optical communication applications.

AlGaAs single laser design technology and coupled-mode technology were used to achieve a higher power phased array laser. Laser grating structure technology contributed to the modulation and single wavelength operation. This should allow the achievement of 4 GHz data rates, with minimum chirp of the laser.

The first operation of a Y-coupled, surface-emitting laser with grating output coupling was accomplished. The laser emitted 1.1 W of power in a single output lobe. The operation of the device in a single spatial mode was a major advancement in phased array technology.

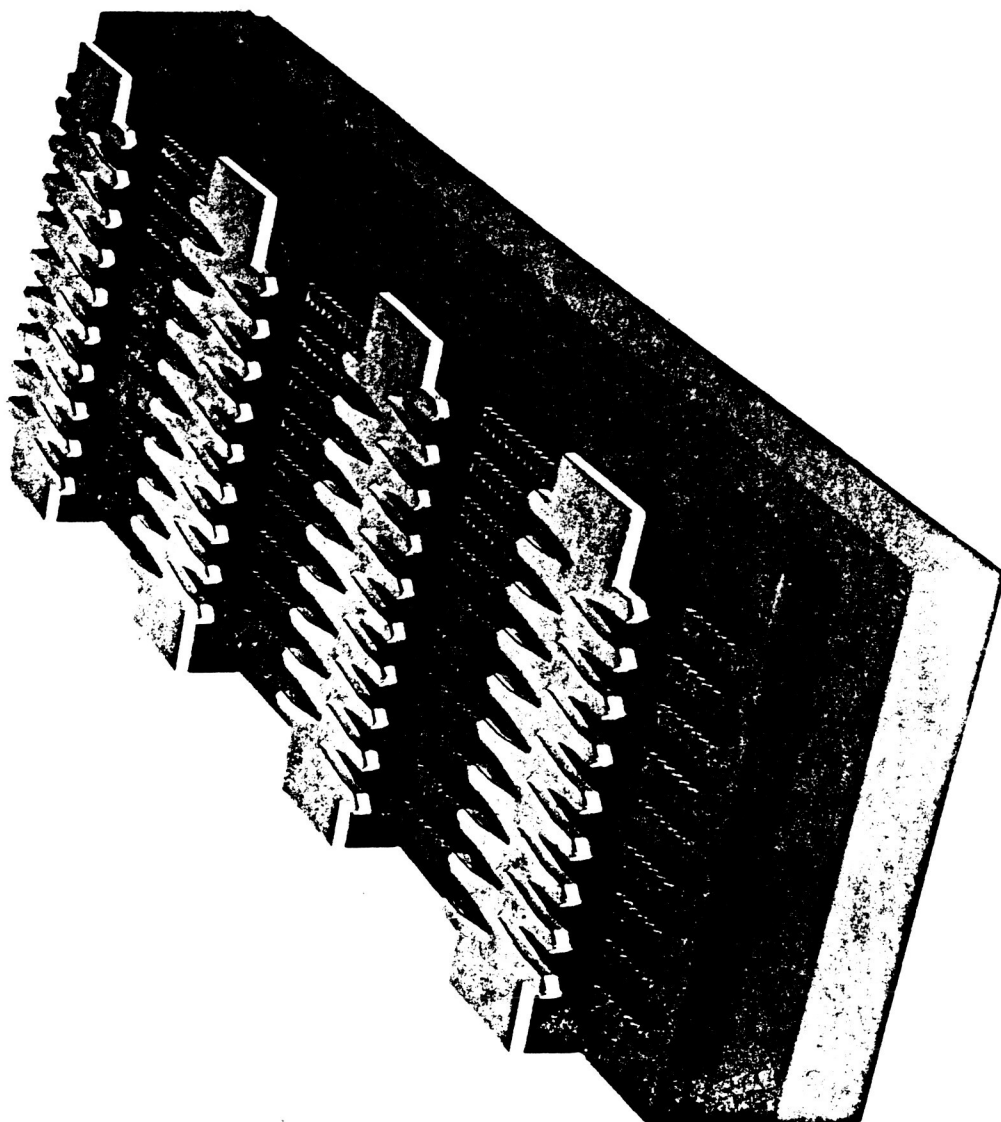
Power limitation for single lasers is 50 - 100 mW. This technology demonstrates higher power semiconductor lasers are possible for near Earth, GEO, and deep space communications. This advancement opens new spectral regions of communications, with attendant reduction in antenna size. This, in turn, will provide a lower power and lighter weight system having GHz communication rate capability.

With the demonstration of power outputs in the watts range and with a single spatial mode, it remains to be demonstrated that the device can be modulated at high data rates while maintaining the spatial mode quality and minimum chirp, when modulated at GHz data rates.

TECHNICAL CONTACT: Herbert D. Hendricks, LaRC (804) 864-1536

PHYSICAL MODEL OF Y-COUPLED WAVEGUIDE ARRAY

CAST



Improved Radiation Patterns of Distorted-Surface Reflector Using Adaptive-Array Compensation

The objective is to develop methods and computer codes which will enable the determination of complex excitation coefficients of array feeds, which will improve the electromagnetic performance of large space deployable reflector antennas whose surface distortion has unacceptably degraded its performance.

Geometrical optics with aperture-integration techniques have been shown to give good results for reflector antennas whose surface is slowly varying (IEEE AP-S 1987 Symposium, pp. 764-767). An earlier technique (NASA TM-87644) was developed that models the aperture as overlapped arrays of subapertures, which reduces the numerical integration problem to a summation with a small number of terms in an efficient and accurate manner.

Recently, a technique (NASA TM-100652) was developed, which utilizes the above techniques in a least-squares procedure, which determines the complex excitation coefficients for the elements of an array feed, and which will, when illuminating a distorted reflector, produce a secondary radiation pattern approximating the performance of an ideal reflector. This technique has been applied to the 15-meter hoop-column antenna to determine the excitation coefficients of a practical feed array, which will compensate for the surface distortion measured in 1985.

This technique will enable the use of electronic means of improving the electromagnetic performance of large space deployable reflector antennas whose performance has become unacceptably degraded. This technique will provide a means of "fine-tuning" the performance after possible mechanical surface adjustments have been implemented.

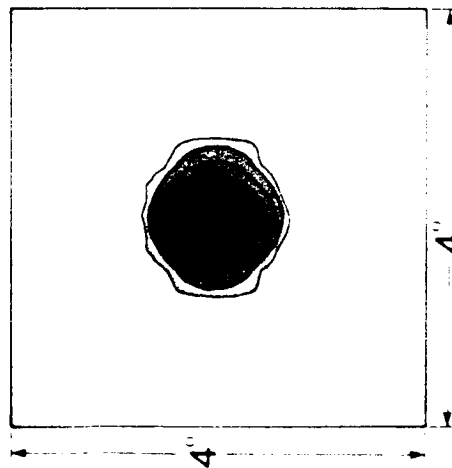
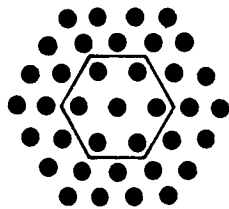
Computer-simulated tradeoffs will be conducted to determine the relative improvements to be realized by electronic compensation versus mechanical adjustments for the 15-meter hoop-column antenna using actual measured surface distortions. Computer simulations will also be conducted to determine possible improvements using a combination of electronic and mechanical compensation.

TECHNICAL CONTACT: M.C. Bailey, LaRC (804) 864-1802

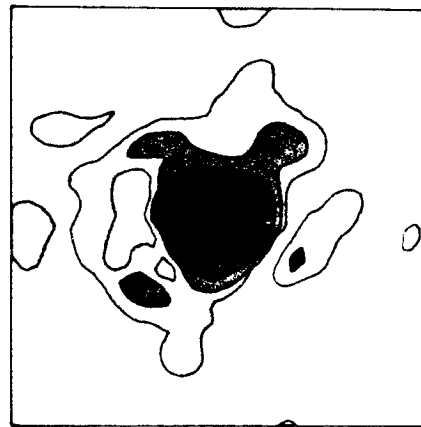
IMPROVED RADIATION PATTERNS OF DISTORTED-SURFACE REFLECTOR CALCULATED USING ADAPTIVE-ARRAY COMPENSATION

CAST

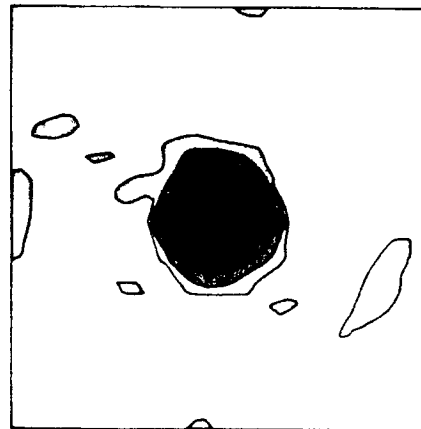
Surface Distortion = 0.061 in. RMS
Frequency = 6.4 GHz



Smooth Surface



Distorted Surface



Feed-Array
Compensation



Theoretical Studies of Cathode Surfaces and High Temperature Superconductors

State-of-the-art computational methods of theoretical quantum chemistry are being successfully used to study the electronic structure of the electron emitting surfaces of barium dispenser thermionic cathodes. These cathodes have important applications in modern high frequency and high power electron beam devices. Technology advancements are demanding higher cathode current densities and longer operating life. Important to the achievement of improved cathode performances is a thorough understanding, down to the atomic level, of the electronic properties of the emitting surface.

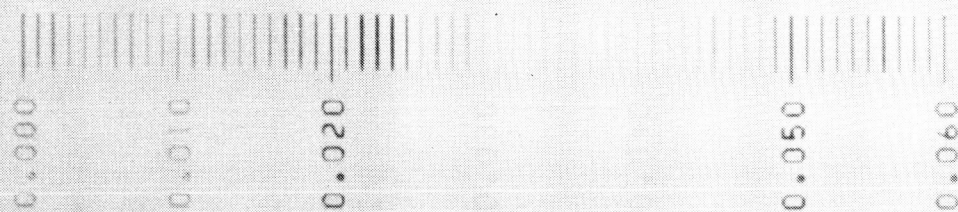
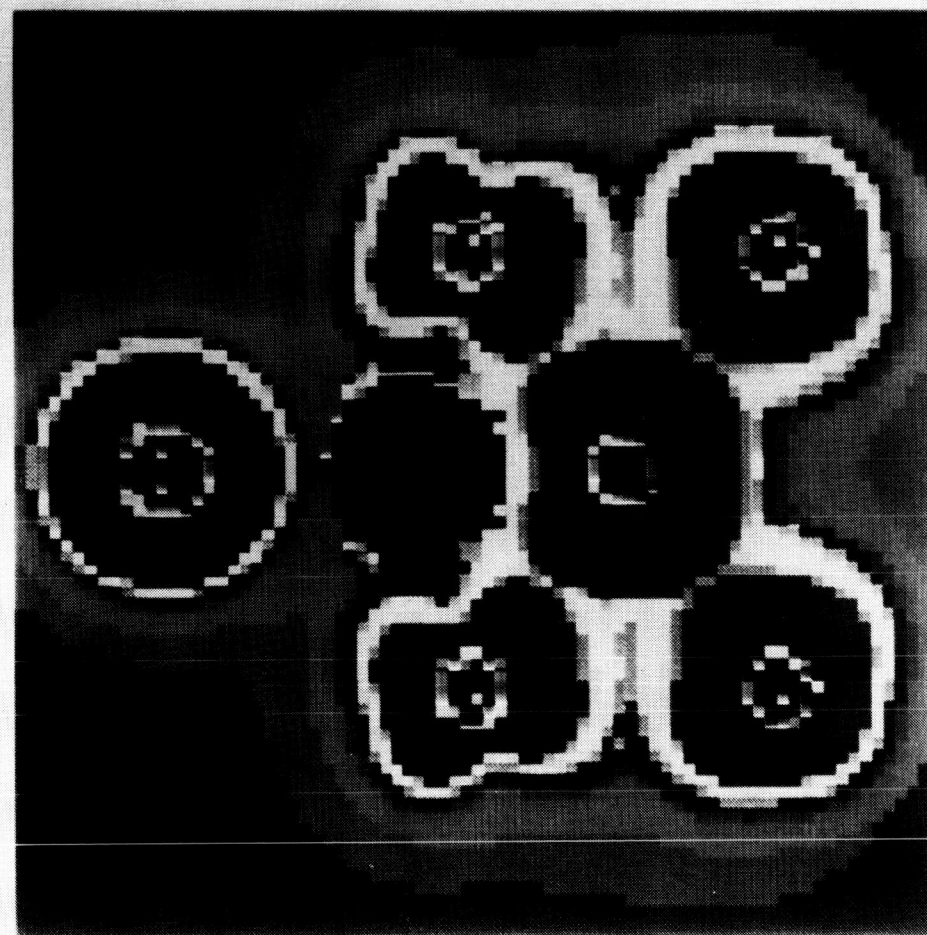
The electron emitting surfaces of Ba dispenser cathodes typically consist of Ba and O chemisorbed on W, Os, or W-Os alloys, which show significant differences in emission enhancement. The quantum chemical studies are now beginning to provide a hitherto unavailable detailed knowledge of the electronic structure and charge transfer characteristics of the chemisorption bonds and a long needed theoretical understanding of the related mechanism of emission enhancement.

The relativistic X-alpha method, with significant improvements made in computational efficiency, has been used to further study the electronic structure of Ba-O-W clusters and also to investigate the interaction of Ba and O with Os and W-Os clusters. The theoretical results for the Ba-O-W system are in good agreement with available experimental data. The calculated valence electron densities of states for W(100) and O-W(100) agree well with solid state band structure calculations and with experimental photoemission studies of occupied and unoccupied states. A comparison of electronic structure calculations for the osmium containing clusters with results for the Ba-O-W clusters shows the following: (1) In all cases the Ba is strongly oxidized whereas the O and metal are in a chemically reduced state. There is a similar large transfer of electronic charge from Ba to the metal substrate but more so if Os is present in the surface layer, thereby causing a larger dipole contribution to the binding energy. (2) For Ba bridge-bonded to two O atoms, which may be the case for the Os and W-Os surfaces, the dipole moment is smaller but the binding energy is greater than for Ba bonded to a single O atom. These theoretical results support the point of view that the greater emission enhancement of the Os and W-Os surfaces relative to pure W is caused by a higher surface coverage due to larger Ba binding energies. A graphical representation of a calculated valence electron density is shown in the figure in the form of a false color image.

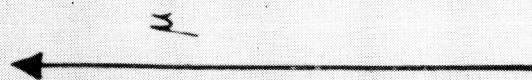
The relativistic X-alpha method is also being used to study the electronic structure of the recently discovered high temperature superconducting ceramics, in which NASA has a string interest for potential space applications. The objective of the study is to understand the mechanism responsible for superconductivity at high temperatures.

TECHNICAL CONTACT: Edwin G. Wintucky, LeRC, (216) 433-3510

BaO/W₉ ELECTRON DENSITY



Net charges	
Ba:	+1.5
(Ba 5d: 0,3)	
O:	-0.2
W _I :	0.0
W _{II} :	-0.3
W _{III} :	-1.0



High T_c Superconducting Microwave Electronics

In order to determine the effectiveness of newly discovered high-T_c superconducting materials in microwave applications, LeRC has undertaken an investigation of the microwave properties of these materials. Thin films are being fabricated and supplied by a number of cooperating institutions including the Naval Research Lab, Ohio State University, Bell Labs, TRW, Oberlin College, University of Cincinnati, and University of Nebraska.

In-house efforts are concentrating on the evaluation of films (critical temperature, critical current at high magnetic fields, magnetic susceptibility, microwave conductance), and the fabrication of passive microwave circuits. The first such circuits have been fabricated using conventional wet-etch methods.

Testing of superconducting circuits will be carried out by conventional measurement techniques and by means of high speed electro-optical sampling in conjunction with the University of Rochester, which should permit evaluation at frequencies to several hundred GHz.

In a related effort, thick superconducting films have been produced in collaboration with LeRC's Materials Division, by means of screen printing with a suspension of superconducting powder.

TECHNICAL CONTACT: R. Leonard, LeRC, (216) 433-3500

HIGH T_c SUPERCONDUCTING MICROWAVE ELECTRONICS

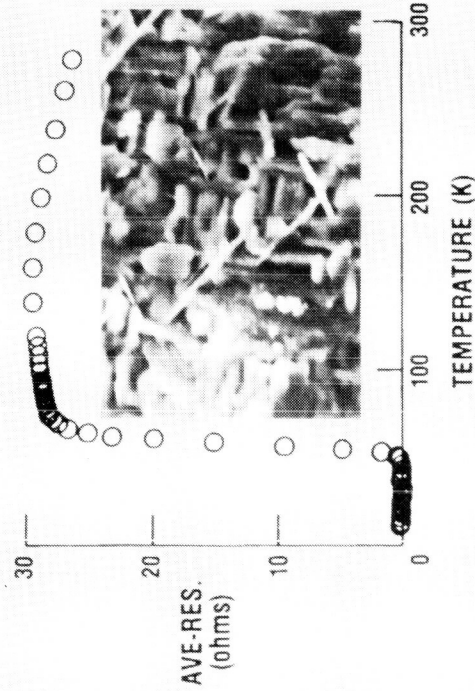
SUPERCONDUCTING
THIN FILM



ETCHED MICROWAVE
CIRCUIT

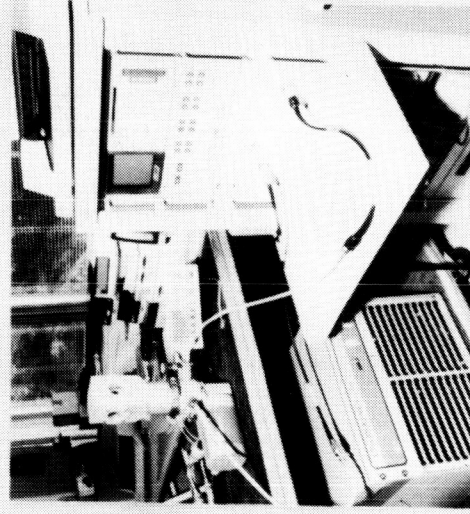
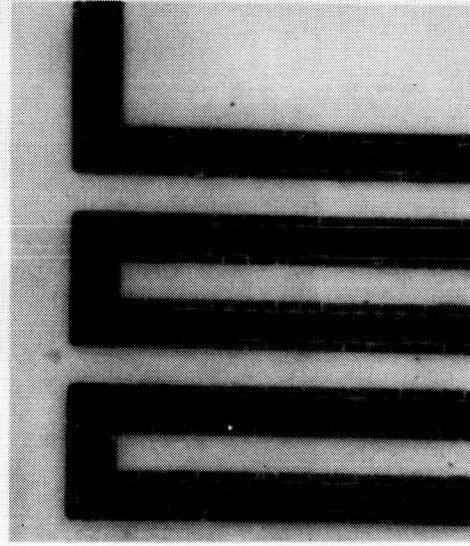


LOW TEMPERATURE
CIRCUIT TESTING



STATUS:

- $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ FILMS ON MgO , SrTiO_3 , $\text{Zr-Al}_2\text{O}_3$ SUBSTRATES
- MULTILAYER E-BEAM EVAPORATION (NASA-LEWIS AND OHIO-STATE)
- MOLECULAR BEAM EPITAXY (NRL)
- THICK FILMS BY SLURRY METHOD



- MICROWAVE TRANSMISSION LINE CIRCUITS FABRICATED BY WET METHOD
- ION BEAM ETCHING TECHNIQUE
- SETUP OF MICROWAVE NETWORK ANALYZER WITH REFRIGERATION SYSTEM

CD-88-35405

Computer Sciences

The Computer Science Program provides advanced concepts, techniques, system architectures, algorithms and software for both space and aeronautics information sciences and computer systems.

The overall goal of the Computer Science Research Program is to provide the technical foundation within NASA for the advancement of computing technology in aerospace applications. This goal will be realized through a program of basic research and experimentation that focuses on developing core skills within the Agency in disciplines critical to NASA and on maintaining a strong university base of fundamental research in aerospace computer science.

The research program is improving the state of knowledge of fundamental aerospace computing principles and advancing computing technology in space applications such as software engineering and information extraction from data collected by scientific instruments in space. Emphasis is being placed on producing highly reliable software for critical space applications.

The program includes the development of special algorithms and techniques to exploit the computing power provided by high performance parallel processors and special purpose architectures. Problem areas of importance include computational fluid dynamics, computational chemistry, structural analysis, signal processing, and image processing. The computer architectures of interest include common and local memory multiprocessors, single-instruction stream/multiple data stream processors, static data flow processors, systolic arrays, and heterogeneous multiprocessors with custom processors. Research is conducted in programming languages and environments, parallel and distributed operating systems and performance measurements.

Research is being conducted in the fundamentals of data base logic. This work has resulted in the development of a common user interface for accessing data from several data bases even when the data bases being accessed have very different structures. This work provides the foundation that will enable NASA space data users access to multiple data bases independent of their physical distribution or structure. This work will reduce the cost of such investigations and enable data base intensive scientific research that would otherwise be unaffordable. Other work is underway to develop and test an expert system that can serve as an assistant to researchers analyzing space derived data.

Research is being conducted to improve techniques for producing reliable computing systems. That work is directed at both reducing the number of faults in software and making systems that are tolerant to faults. New approaches and methods for software management and engineering have been devised and are not being evaluated under real working conditions. Future objectives in a new software engineering initiative will include research on the theoretical foundation, and extending and evaluating approaches for developing reliable complex software.

The Computer Sciences Program is coordinated with the Space Station's Software Support Environment (SSE) and the DOD sponsored Software Engineering Institute (SEI) and ADA. NASA also participates with DOD on several advisory and technical committees.

PROGRAM MANAGER: Dr. Paul H. Smith
 NASA/OAST/RC
 Washington, DC 20546
 (202)453-2753

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The Software Management Environment

The Software Management Environment (SME) is a software tool designed to assist a manager in monitoring, analyzing, and controlling an ongoing software project. The major functions of the SME include the ability to track software project parameters; to analyze the differences between the current project's development patterns and the expected development pattern within the environment; to predict characteristics such as milestones, cost, and reliability; and to assess the overall quality of the project's development process. To provide these functions the tool continually examines available development data from the project of interest including manpower, software changes, computer utilization, and completed milestones and compares this information to data from past projects and to a model of the "typical" project.

Providing a set of capabilities that allow a manager to acquire pertinent, up-to-date information on the quality of a development project, the SME integrates much of the experience, results, and knowledge of major software engineering research that has been carried out in the Flight Dynamics Division at Goddard. This research has provided a clearer understanding of the software development process within this one particular environment and the factors that lead to successful software projects. By integrating this knowledge, the SME enables software managers to better understand, control, and analyze their software development projects.

Research accomplishments for 1988 include: completion of the man-machine interface for the SME; interaction of the SME to the corporate data base; integration of software models and project data into a demonstrable system; and the development of algorithms for predicting future project status. During the next year work will focus on completing all major components of the system, including integrating an expert system for project analysis. The system will then be evaluated using three or four flight dynamics projects with the evaluation and system completion expected at the end of 1989.

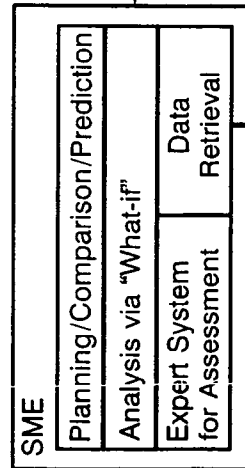
TECHNICAL CONTACT: Jon Valett, GSFC (301) 286-5316

SOFTWARE MANAGEMENT ENVIRONMENT (SME)

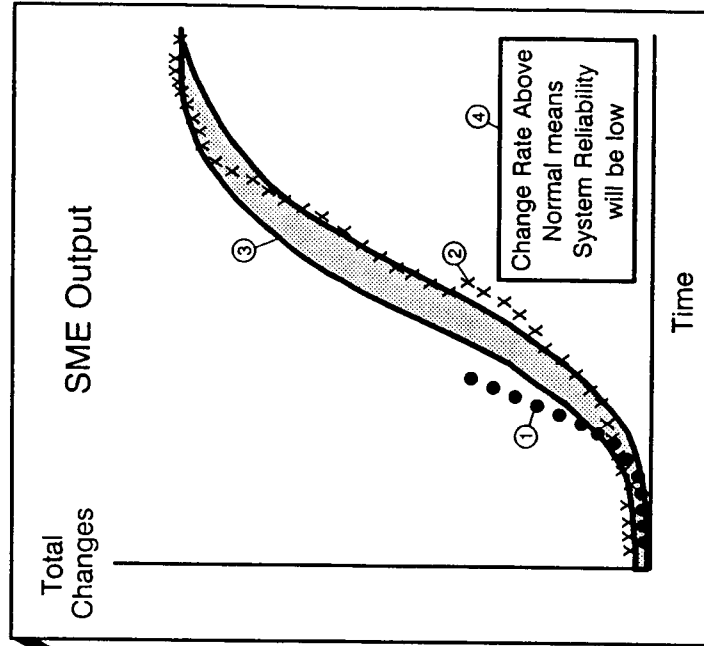
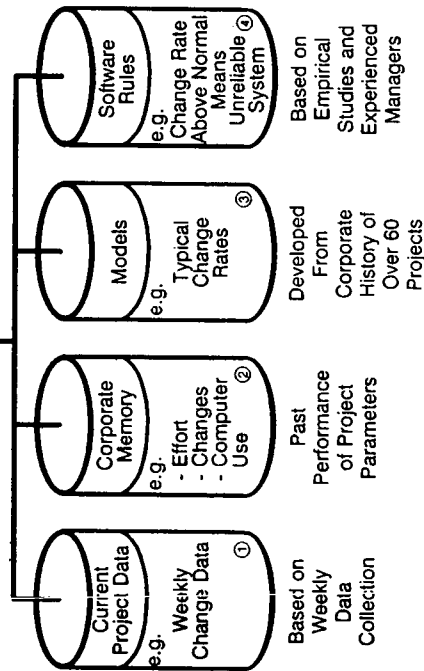
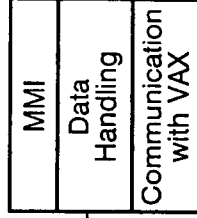
OST

- Demo versions of all major components 9/88
- Evaluate using 3 flight dynamics projects 12/88
- Completed SME 9/89

VAX



PC



VLSI technology has made the computer architect's design space very large, requiring many design tradeoffs. These tradeoffs must be guided by the applications for which the architecture is being designed. An architectural design must take into account the actual applications because the use of designer's intuition can lead to less than optimal designs. However, detailed simulations of full applications is prohibitively expensive. Therefore a hierarchy of design tools is required by the computer architect.

Stanford University is developing several of these needed tools under a grant with Ames Research Center. Depicted in the figure is the Architect's Workbench (AWB), which provides very efficient simulation of processor/cache using approximate hardware descriptions with actual higher level language application programs. The AWB supports Pascal, FORTRAN, and "C". The AWB (release 1.5) allows processor "floorplanning" and approximate performance evaluation with immediate turnaround rather than the weeks of effort currently required per design iteration. The AWB will also be modified to account for the effects of pipelined instructions.

Stanford has also developed an analytic model for concurrent systems. Parallel computation consists of tasks with precedence relationship expressed as a series -- parallel directed acyclic graph. Resources are modelled as a network of queues. Residence time, task completion time, queue length and system performance can be evaluated by an iterative method of queuing networks.

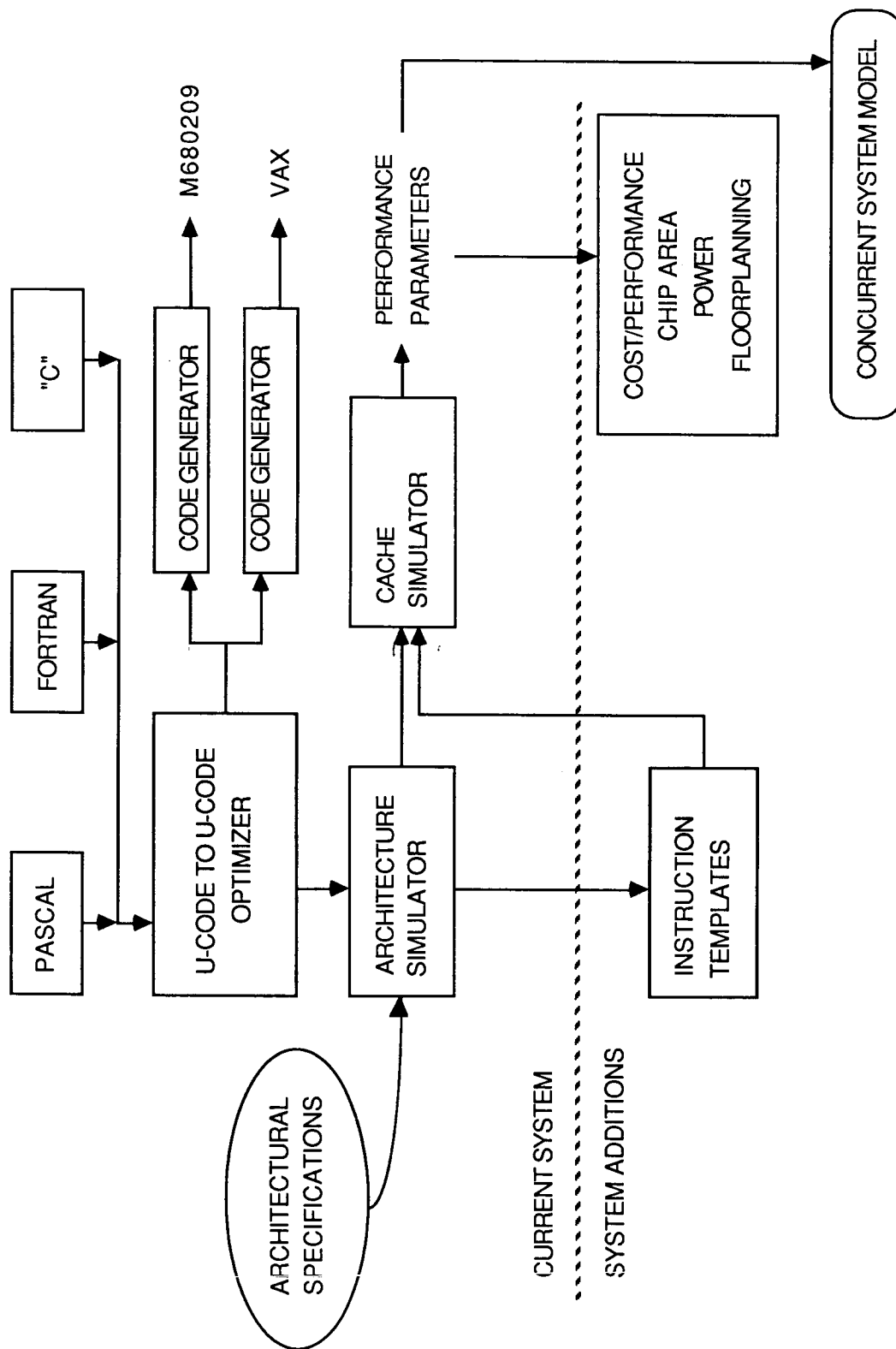
Stanford plans to enhance the AWB effort by adding: 1) an ADA language front end; 2) a pipeline break analyzer, allowing application performance evaluation to the cycle level; 3) evaluation of various concurrent computer architectures and pipelined processors using both simulation and previously developed analytic models.

These extensions, as they are completed, are tested and verified with actual applications and existing computer systems. AWB release 1.5 is available in August 1988; the pipeline analyzer extensions are planned for release in June 1989.

TECHNICAL CONTACT: K.G. Stevens, Jr., ARC (415) 694-5949

ARCHITECTS WORKBENCH

—OAS-T



Autonomous Exploration

Vehicles for planetary exploration and remote Earth sensing will carry multiple, increasingly complex scientific imaging instruments including imaging spectrometers capable of collecting several hundred channels of data for each planet. This data is required both for geological or atmospheric survey, and for choosing desired traversal paths and potential samples on a ground-roving vehicle. However, limitations of transmission bandwidth will allow only a fraction of the collected data to be transmitted to Earth, and existing analysis techniques allow even less to be analyzed in real time. To achieve the scientific goals of an exploratory mission, incoming data sets must be analyzed and fused in real time, and autonomous decisions produced.

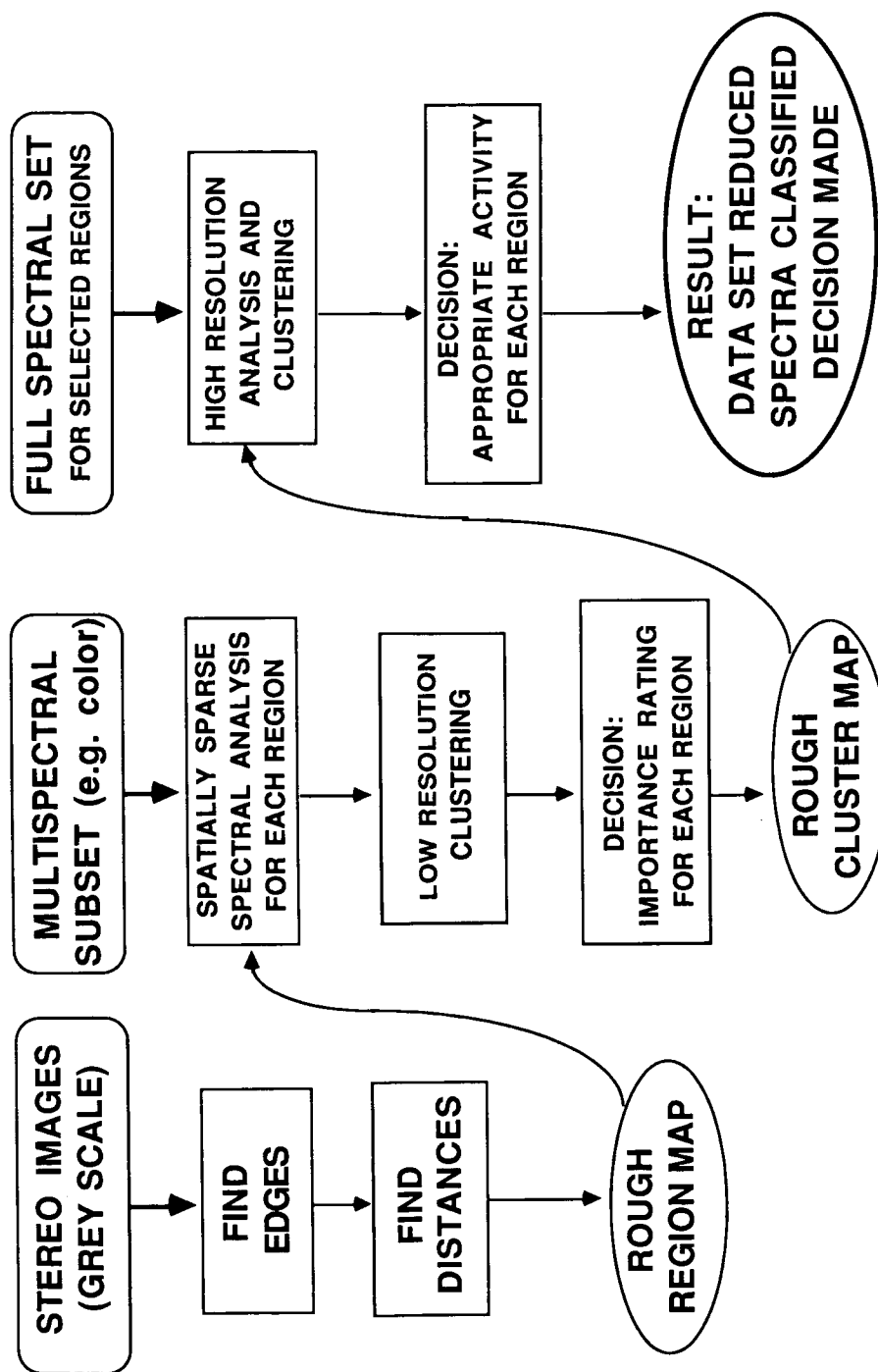
The objectives of this program are to develop and implement autonomous, real-time methods of high dimensional image data reduction and information extraction. The system must be capable of fusing data from multiple sensors and providing decisions on instrument configuration and resource allocation based on the incoming data and scientific objectives. The program will provide enabling technology for the automatic data interpretation and planning functions required of an autonomous exploration system such as a Mars rover.

This work continues the development of artificial intelligence techniques originated in the Spectrum expert system and extended here to work in real-time without user interaction. A prototype system currently incorporates artificial neural networks, rule-based artificial intelligence techniques and mathematical analysis programs to perform the following functions:

1. Spatial segmentation of an image based on distance of objects from the viewer (stereo matching) and location of edges.
2. Classification of spectra in each region using a selected subset of the total spectral channels.
3. Assignment of interest level to each region based on class information and scientific goals.
4. Resampling and finer classification of interesting regions using total spectral resolution.
5. Autonomous decision making to select the next action (e.g. transmit an image, take a sample from an area.
6. Reduction of the high dimensional image to a small set of regions descriptors, conveying object location, outline, distance, and geological class.

TECHNICAL CONTACTS: Susan J. Eberlein, JPL (818) 354-6467
Jerry E. Solomon, JPL (818) 354-2722

(506-45-01-01)



WITH BROAD GEOLOGICAL CLASS AND GOAL DEPENDENT INTEREST RATING

Intelligent Data Management Processes

The objective of the Intelligent Data Management project is the development of intelligent data fusion and representation systems that bring together emerging software technologies under the umbrella of an expert system shell with embedded 3-D graphics, communications, and spatial and relational database systems. It is based on a distributed architecture with value added services for managing, meta data (information about data), spatial data, and object-oriented data in the context of a user's domain. This will allow for the development of more sophisticated, dynamic models that have a better user interface than is currently available for interacting with and interfacing to very large and complex databases.

The technical areas being addressed in this research are: 1) Highly efficient search techniques of very large databases; 2) Intelligent distributed information system control and management; 3) Development of data structures that allow representation of different user and database views; 4) Query formulation based on natural language processing; 5) Automatic data cataloging and characterization; 6) High-level graphic user/system interaction and understanding; 7) Spatial data management supporting multiple levels of representation; 8) Knowledge acquisition and machine learning to create a very high-level expert system programming environment.

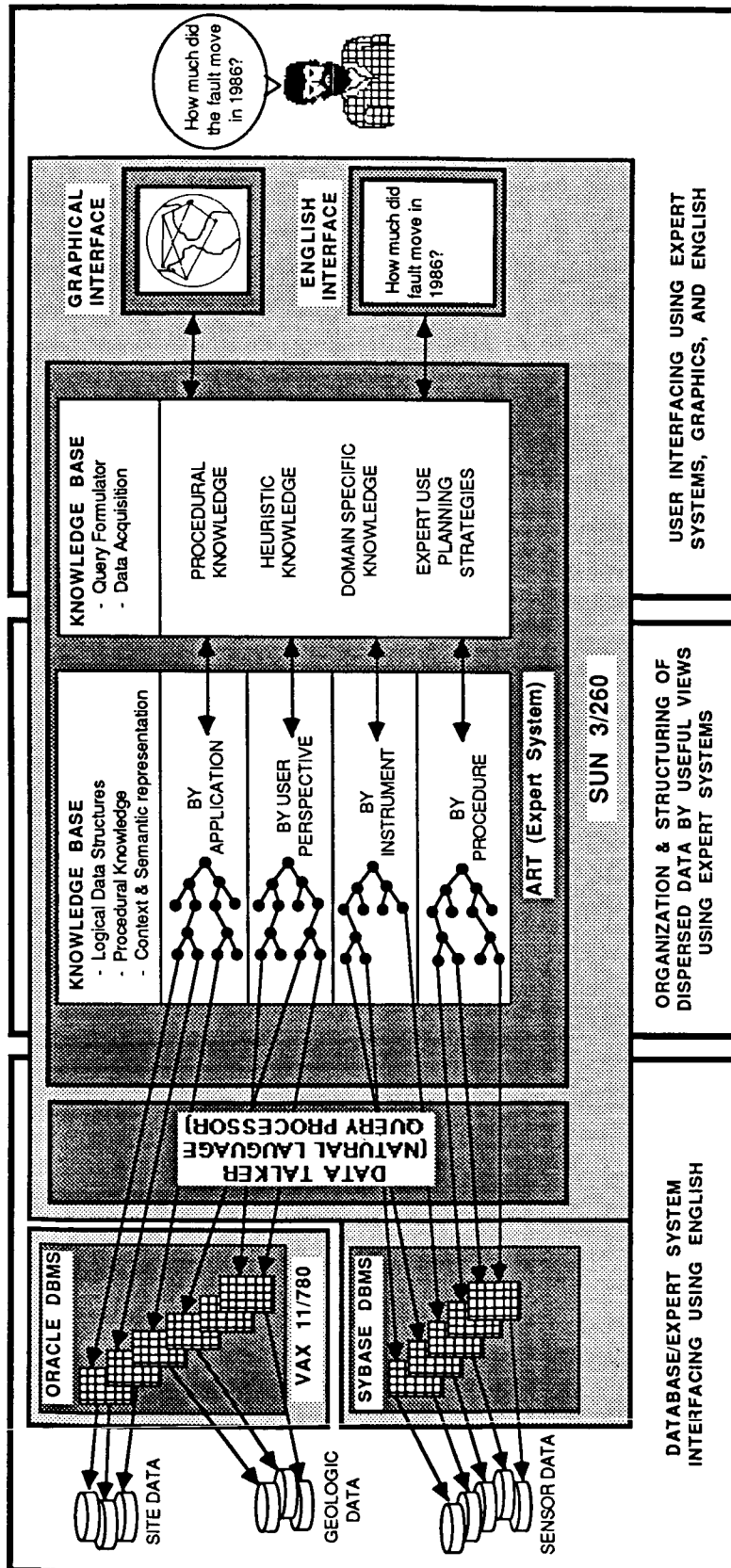
This research will result in the development of a next generation intelligent data fusion and visual representation system capable of meeting the data management and representation demands required through the space station era by emphasizing the integration and customization of many commercial development tools and languages. We are attempting to build a data fusion system that has an intelligent controller manipulating the subordinate, commercial packages. As a by-product of this paradigm, the scientific knowledge garnered from each principal investigator on the system would automatically be codified in the knowledge views. Thus, by reducing the costs of data access through intelligent control, this, in theory, will facilitate the sharing of specific knowledge as well as data among multiple disciplines.

An advanced prototype has been developed on a Sun 3/260 with 3-D graphics, advanced natural language capabilities, Automatic Reasoning Tool (ART) expert system, two domain-specific knowledge bases and Sybase DBMS. Integrated, these tools provide a powerful intelligent interface to two scientific operational databases (Crustal Dynamics and Astrophysics) that allows a user without any previous training or experience with the system to rapidly search, access, manipulate, and display specific remotely distributed data of interest without having to understand the database language, architecture or knowledge of the specifics of the data itself. Coding has begun that will allow a domain expert to customize, teach and store his own strategies and results in his own customized knowledge base without any advanced training.

TECHNICAL CONTACT: William J. Campbell, GSFC (301) 286-8785

INTELLIGENT DATA MANAGEMENT PROCESS

OAST



OBJECTIVE

Development of an Intelligent System That Is Based On A Distributed Architecture With Value Added Services For Managing, Meta Data (Information About Data), Spatial Data, & Object Oriented Data In The Context of A User's Domain

BENEFITS

- User Does Not Have To Understand The Database Architecture, Query Language, or Data Content
- Will Allow Scientists to Access Multidisciplinary Data In A Common Environment
- Supports An Understanding Of The Data In Context By User, Application, & Source

FY 88 ACCOMPLISHMENTS

- Installed & Customized Expert System to SUN Workstation
- Installed & Customized Natural Language Query Processor "DATA TALKER" on SUN Workstation
- Installed, Customized, & Interfaced 3D Graphics For Two Scientific Operational Databases
- Knowledge Engineered & Interfaced Astrophysics DBMS Using ART
- Demonstrated The Entire Prototype With Two Scientific Operational Databases
- Tested & Validated IDM Concept Using Selected Noncomputer Oriented Scientists
- Presented & Published Results Of Prototype Research Effort

Distributed Access View Integrated Database System

NASA Space scientists and administrators have to learn many different access methods in order to obtain data. This is due to the plethora of: 1) devices (IBM, VAX, CDC, SUN, CRAY, etc.); 2) operating systems (Berkeley UNIX, System V UNIX, VAX VMS, IBM OS, etc.); 3) database management systems (Oracle, Ingres, Sybase, Omnibase, IMS, Adabase, etc.); communications alternatives (ARPA Net, SPAN, Bit Net, Local Area Net, etc.); and 5) data center protocols (National Space Science Data Center, Infrared Processing and Analysis Center, etc.). Access to distributed data is a major problem facing all segments of NASA, including access to complementary science observations in mission databases and access to space system engineering data and project management information at centers and contractor subsystem facilities.

This research deals with the development of a uniform method for accessing data that is layered on top of existing systems. This method is a software system called the Distributed Access View Integrated Database (DAVID) system.

The first version of the "main room" software for the library layer, which rests on top of the DAVID engine, was built and tested. The library layer makes a typical local area network look to the user as an ordinary library. The main room is a gateway machine into the local area network and the main room software makes the gateway machine appear to look like the main room of a library (i.e., administration, reference, catalogue, circulation, reproduction, and union library desks.).

The first version of the "reading room" software for the library layer was built and tested. All non-main room machines in the "library" are called reading rooms. These are the machines in which the actual data is stored. The reading room software allows the user to read or browse through the data before making a request for a subset (at the reproduction desk of the main room).

In conjunction with the Astrophysics Division (Code EZ), the DAVID Engine and main room software was ported to several Astrophysics data centers. This is in preparation for a major demonstration of a proposed Astrophysics Data System. The centers involved are: Infrared Processing and Analysis Center (IPAC) at Cal Tech; Smithsonian Astrophysical Observatory (SAO) at Harvard University; International Ultraviolet Explorer (IUE) Facilities at GSFC and University of Colorado; National Radio Astronomical Observatory (NRAO) at Charlottesville, VA; National Optical Astronomical Observatory (NOAO) at University of Arizona; Space Telescope Science Institute (STScI) at Johns Hopkins University; and the National Space Sciences Data Center (NSSDC) at GSFC.

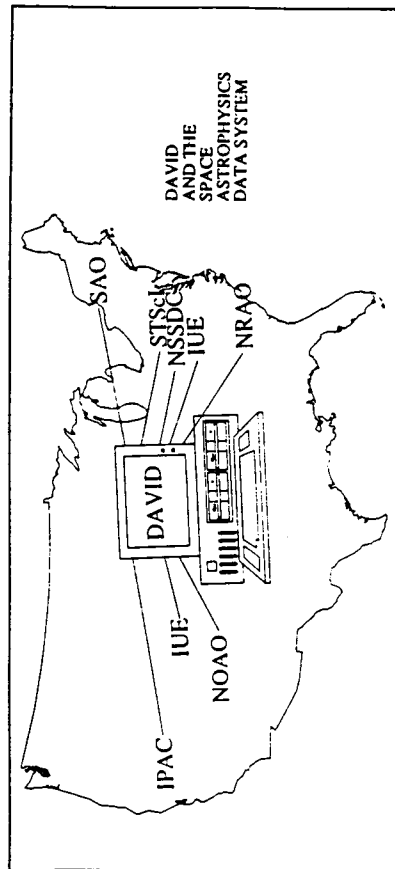
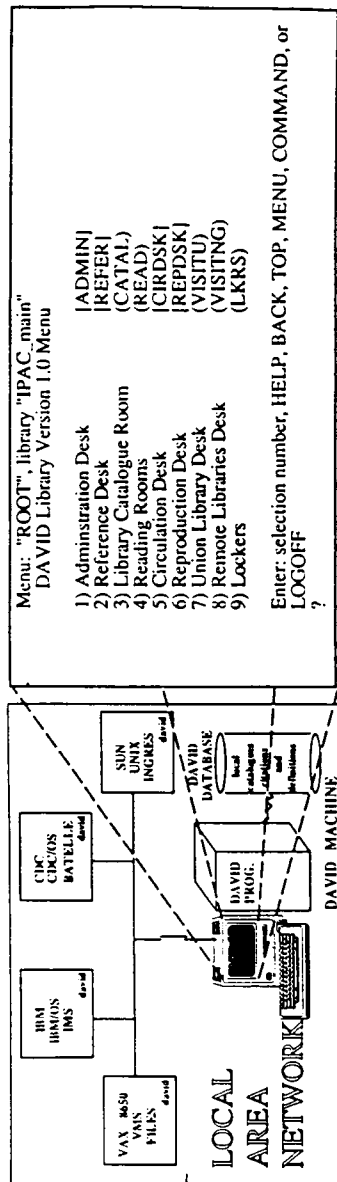
At the current time the DAVID efforts are proceeding in two major directions. Work will continue with the Astrophysics Division on their Distributed Data System, which uses DAVID as its internal vehicle for locating and accessing data. Based on these experiences with this application, improvements will be made to both the DAVID engine and the library layer.

TECHNICAL CONTACT: Dr. Barry Jacobs, GSFC (301) 286-5661

DISTRIBUTED ACCESS VIEW INTEGRATED DATABASE (DAVID)

OASST

PROBLEM: • NASA SCIENTISTS AND ADMINISTRATORS HAVE TO LEARN MANY DIFFERENT SYSTEMS AND ACCESS METHODS IN ORDER TO OBTAIN DATA.



ACCOMPLISHMENTS

- BUILT AND TESTED VERSION 1 OF "MAIN ROOM" SOFTWARE FOR THE "LIBRARY LAYER" ON TOP OF THE DAVID ENGINE.
- BUILT AND TESTED VERSION 1 OF THE "READING ROOM" SOFTWARE FOR THE "LIBRARY LAYER" ON TOP OF THE DAVID ENGINE.
- INSTALLED DAVID SOFTWARE AT ASTROPHYSICS DATA CENTERS- IPAC, SAO, IUE, NRAO, NOAO, STScI & NSSDC.

CURRENT WORK

- WORK WITH ASTROPHYSICS DIVISION (CODE EZ) ON BUILDING A DISTRIBUTED DATA SYSTEM USING DAVID AS A VEHICLE FOR ACCESSING DATA.
- MAKE IMPROVEMENTS TO DAVID ENGINE/ LIBRARY LAYER BASED ON LESSONS LEARNED.

A Systolic Ray Tracing Processor

Ray Tracing is the current method for the state-of-the-art production of realistic computer-generated imagery. Traditionally, speed is the missing element for making ray tracing images a practical option. This research seeks to design and construct a ray tracing processor based on the systolic array architectural concept, which would break this speed barrier. This would mean a new frontier for graphics applications in a wide range of scientific disciplines.

Ray tracing algorithms are not generally amenable to vectorization, so that even the high power vector processors of current supercomputers cannot produce the desired performance. However, almost all of the computational time in ray tracing is spent in ray-object intersection calculations, and therefore a special purpose systolic ray tracing engine is extremely effective in speeding up the entire computation.

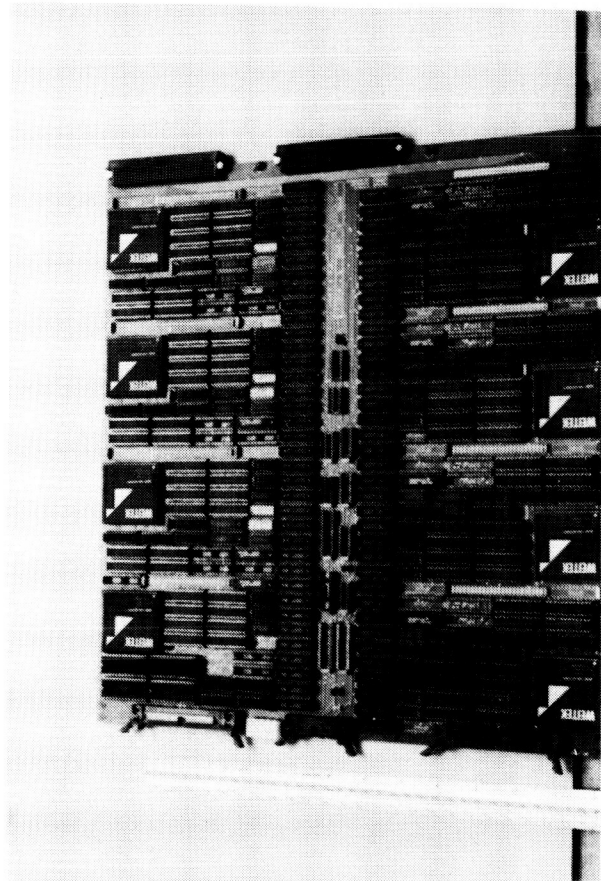
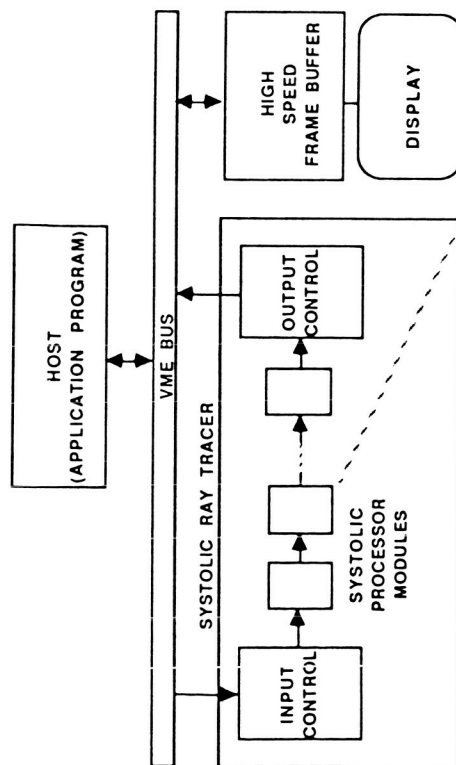
The Systolic Ray Tracer (SRT) is designed for use in conjunction with existing ray tracing software packages. Operationally, the SRT is user-transparent; changes necessary to support the ray tracing engine in most graphics codes amount only to a simple change in the ray/patch intersection subroutine call. The SRT is set up to handle fourth-order non-uniform rational B-splines (NURBS) in the ray/patch calculations. Software drivers for other packages are expected to be available in the future.

The key concept in achieving practical ray tracing in workstation environments is proper division of labor between the host computer and the ray tracing engine. Before a ray/object calculation is initiated, a sieving process running in the host is used to discard rays that have no chance of hitting the objects of the scene to be rendered. The percentage of rays that are sieved out is scene specific, but typically between 1% and 10% of the rays fired will remain. Users can employ their own sieving methodologies or use the one provided in the CGL package from the University of Waterloo.

The SRT implements in hardware a proprietary algorithm for computing the intersections between a ray and a bicubic patch in graphics ray tracing. This algorithm computes all intersections of a ray and a bicubic patch. Because of the systolic pipe a new set of ray/patch calculations can be started every 120 ms. The SRT, implemented as a four-board set, performs 32-bit floating point operations at a sustained rate of 560 MFLOPS. Due to the sieving, this is all useful work, and completed pictures can be produced in a few seconds. Stereo images are easily produced, and since all ray intersections are calculated, the volume of objects in a scene is immediately available. A working prototype will be available in the fourth quarter of 1988.

TECHNICAL CONTACT: K.G. Stevens, Jr., ARC (415) 694-5949

RENDERING SYSTEM UTILIZING THE SYSTOLIC RAY TRACER



"BOIDS" A Visualization Testbed

The objective of this research was to develop an environment in which custom visualizations of scientific data can be easily implemented and evaluated.

A high-level "visualization language" enables researchers to create new visualization models. This language is specifically designed for this application and avoids the syntactic overhead of more traditional computer languages.

A fluid flow might be illustrated using a set of triangles, with each one positioned along the local velocity vector and co-planar to the local vorticity vector. This model can be implemented using only eleven lines of "visualization language."

The significance of this research is that scientific insight depends upon highly informative visualizations of the raw scientific data. The language therefore enables scientists to rapidly create new visualization models specifically tailored to their needs.

Future plans include development of a more complete visualization language, which will give more expressive power to the scientist; thereby supporting more useful visualizations.

TECHNICAL CONTACT: Jeff P.M. Hultquist, ARC (415) 694-5000

**BOIDS WHICH TRAVERSE FLOW FIELD LINES AND DISPLAY OTHER
FLOW FIELD VARIABLES VIA CHANGES IN ORIENTATION SIZE,
SHAPE OR COLOUR**



Concurrent Processing Research

The objective is to perform fundamental research by developing algorithms that map efficiently to computers with very large numbers of processors and high speed connections between the processors, for application to NASA problems. The approach taken is to implement a wide variety of applications on the highly parallel SIMD architecture of the Massively Parallel Processor (MPP) to understand the robustness of this type of computer.

During FY88 two new algorithms were demonstrated to run in the MPP array unit: hologram computation and neural network simulation. In addition, two algorithmic approaches first demonstrated in FY87 were enhanced considerably: cellular automata and general ray tracing. All are extremely compute intensive and map very well to the MPP's mesh architecture. The performance of all these algorithms benefits greatly from the bit-serial nature of the MPP processors.

Hologram Computation: As an initial step in the development of the hologram algorithm, the hologram of a point was computed, requiring one second of MPP time. High resolution computed holograms may one day give NASA's scientists and engineers the ability to view large amounts of data presented in three dimensions. This is written in MPP Pascal.

Neural Network Simulation: Neural networks were implemented and used to solve clustering problems and multiple line fitting problems. These computationally hard (NP-complete) problems are typical of a class of problems in data fitting, pattern recognition, and computer vision for which good, but not necessarily optimal solutions are required. This work is performed in collaboration with the Center for Automation Research at the University of Maryland and written in MPP Pascal.

Cellular Automata: In FY87 a generalized hexagonal grid cellular automata for application to magnetohydrodynamic simulations was implemented and clocked at 850 million site updates per second. During FY88, the model was demonstrated to simulate fluid flow around various shaped obstructions. Written in MPP Pascal the same simulation runs on a FPS-164 array processor at a rate of 1 million site updates per second and on the RAPI (a machine specially designed for cellular automata) at a rate of 40 million site updates per second. This is performed in collaboration with Goddard's Laboratory for Extraterrestrial Physics.

General Ray Tracing: In FY87 general ray tracing was first demonstrated on the MPP, based on an algorithm that finds the intersection of light rays and objects in a three-dimensional space. During FY88, the approach was enhanced to allow multiple generations of rays. This is performed in collaboration with Goddard's Laboratory for Terrestrial Physics and written in MPP Parallel FORTH.

In FY89 plans are to further optimize and enhance the parallel ray tracing and neural network simulation techniques; to develop additional graphics and data visualization techniques; to demonstrate string search algorithms on the MPP for use in database searches or analysis of DNA; and to implement the simulation of flow reactors, such as is used to perform molecular evolution simulation.

TECHNICAL CONTACT: Dr. John E. Dorband, GSFC (301) 286-9419

CONCURRENT PROCESSING RESEARCH

ACCOMPLISHMENTS

Demonstrated running in the MPP array unit:

- Hologram Computation
- Neural Network Simulation
- Cellular Automata (enhanced)
- General Ray Tracing (enhanced)

BENEFITS

- Scientific Data Visualization
- Solid Modeling
- Thermal Modeling of Spacecraft
- Higher Speed Fluid Simulation
- Foliage Canopy Modeling
- Animated Graphic Generation for Robotics



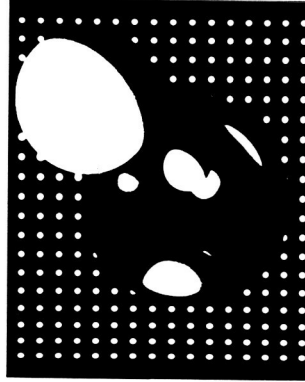
COMPUTATIONAL HOLOGRAPHY

The hologram of a point.
Potential applications include 3-dimensional visualization of engineering and scientific data.



CELLULAR AUTOMATA

Generalized hexagonal grid cellular automata simulating fluid flow. Obstacles inserted in flow produce expected flow effects.
Potential applications include higher speed fluid simulation.



GENERAL RAY TRACING

The enhanced ray tracing algorithm now allows multiple generations of light rays.
Potential applications include foliage canopy modeling and thermal modeling of spacecraft.

Software Analysis and Applications

The objective of this research is the understanding of basic principles underlying and construction of new software development methodology needed for cost effective development of complex, reliable systems for NASA. The focus is on component reuse, software development environments and tools, and non-standard development paradigms (e.g., prototyping).

The approach in each of these areas is as follows:

- 1) Reuse - Develop a research database of reusable components (based on a rigorous model) and use it to test and refine criteria for inclusion/selection of components, measures of reusability, and the basic model structure.
- 2) Environments and Tools - Develop a set of tool building components for creating lexical analyzers, parsers, transformers and formatters, called PET (Programming Environment for Tools) and verify it using real applications.
- 3) Paradigms - Research current uses of non-standard software development paradigms in laboratory projects, and the factors in the project environment that make these paradigms effective.

Progress and accomplishments have been made in the three target areas:

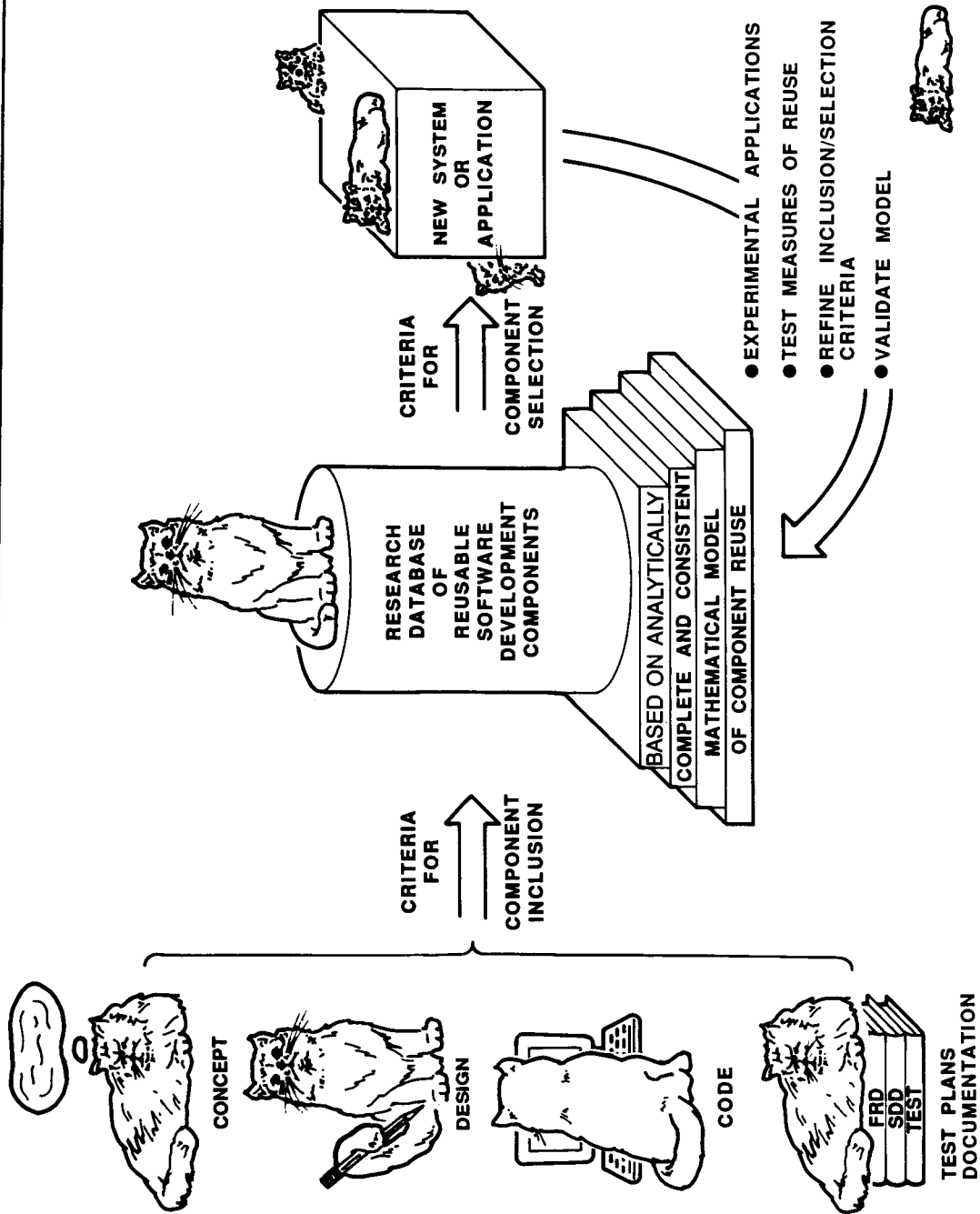
- 1) Reuse - Modeled component reuse, focusing on reclaiming software development elements (e.g., design, code, documentation, test plans) from existing projects and constructed example components taken from actual projects.
- 2) Environments and Tools - Built tool modules, using PET, that analyze significant dialects of FORTRAN code and re-synthesize the code noting and/or correcting eleven instances of non-standard constructs.
- 3) Paradigms - Completed exploratory investigation of paradigms (prototyping, incremental development) being used in on-going projects, and analyzed contrasting cases for common threads, problems, solutions, successes and failures.

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Future plans for the project include: 1) construction of a research database of reusable components based on the model and use of it to evaluate and refine criteria for inclusion/selection of components, measures of reusability, and the basic model structure; 2) use of PET to extend the capability to note and correct non-standard constructs and explore applications of PET to data flow analysis, the structuring of unstructured code, and the support of interactive code analysis; and 3) design and conduct of an experiment to confirm the common elements of paradigm structure, project environment, and their relationships found in the current investigation, and use the valid elements to design generic paradigms.

TECHNICAL CONTACTS: Ann Griesel, JPL (818) 354-9289
Charles Lawson, JPL (818) 354-4266

COMPONENT REUSE RESEARCH



Software Engineering Research

The Software Engineering Research Center (SERC) is an effort by the Johnson Space Center (JSC) and the University of Houston Clear Lake (UHCL) to identify and evaluate advancements in computer systems and software engineering concepts, principles, methodologies, tools, and environments as applicable to the Space Station Program. A key research issue is integration of the three principal environments for embedded systems: Host, Target, and Integration.

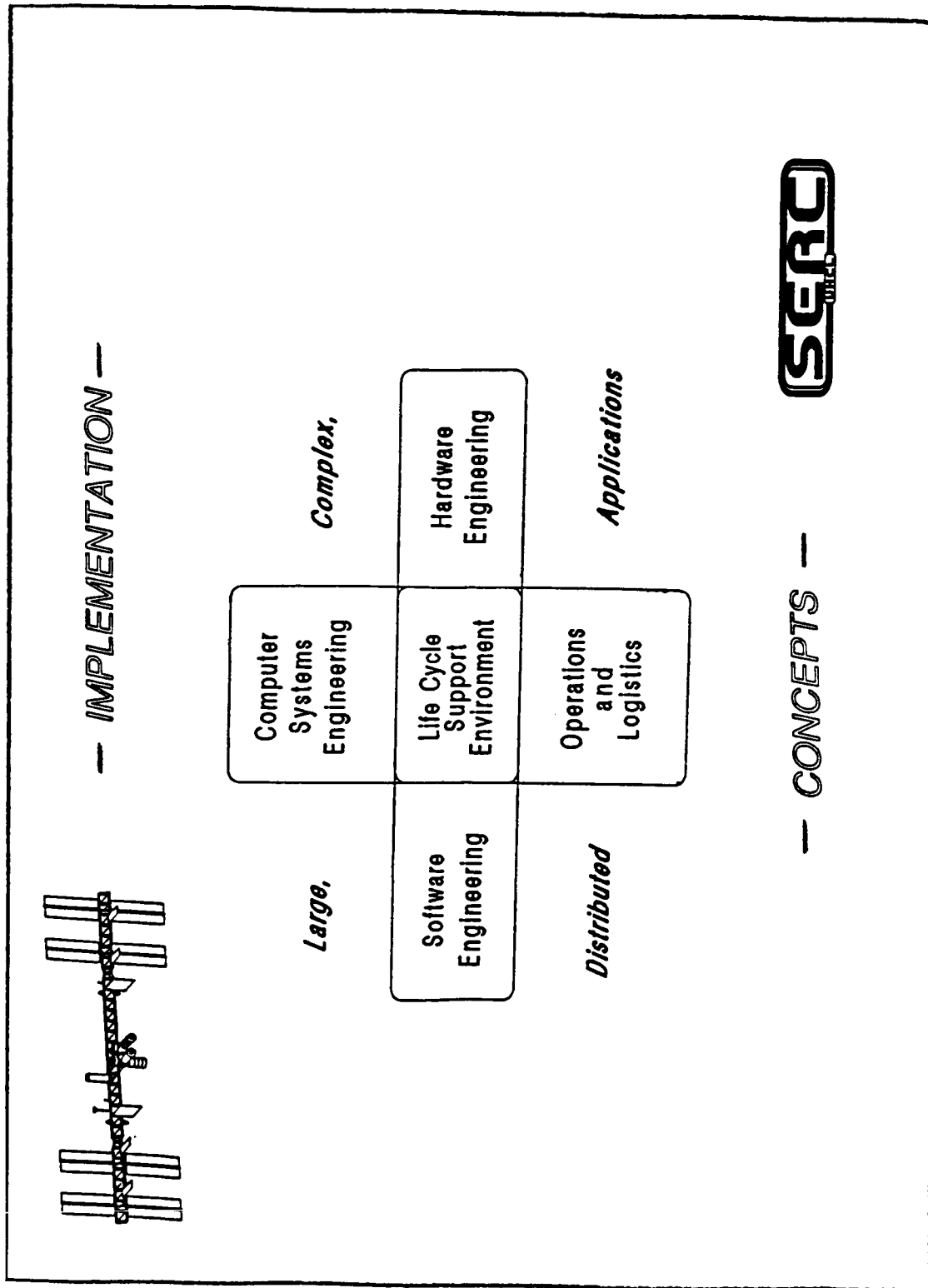
The academic capabilities of UHCL are combined with the pragmatic approach of JSC to investigate:

- 1) Proof-of-Concept Prototype of a Portable Common Execution Environment to support distributed Ada programs on heterogeneous processors; 2) development of a Life Cycle Model for the support of large, complex, distributed systems; 3) automatic software verification tools; 4) evaluation/integration of commercial off-the-shelf systems analysis and design tools; 5) fault-tolerant Ada software for mission and safety critical components; 6) distributed Ada model implementation with a tailorable run-time environment; and 7) Ada programming support environment government data base.

The conceptual model of the Life Cycle to support large complex distributed systems is complete and the implementation is currently under study. The Portable Common Execution Environment is in initial design phase. Evaluation of Systems Analysis Tools is under way. We have played a major part in the development of the Catalog of Interface Features and Options for Ada Run-Time Support Environments. A distributed Ada communications level prototype was successfully demonstrated. The Software Engineering Ada Database is operational and data is being loaded.

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SOFTWARE ENGINEERING INTEGRATION CONCEPTS APPLICABLE TO THE SPACE STATION FREEDOM



An Empirical Comparison of Fault Tolerance and Fault Elimination

This research compares software fault tolerance and software fault elimination techniques as approaches to improving software reliability. In particular, empirical data is sought addressing the appropriateness of: 1) reducing standard testing procedures on the assumption that voting of redundant software achieves a high degree of fault-tolerance in operational software; and 2) using voting of the redundant software as a test oracle in the validation process.

A problem specification adapted from the aerospace industry formed the basis for multiple implementations by senior-level computer science students working in two-person teams. Eight versions of moderately sized programs (1186 to 2489 lines of code) were independently designed, coded, and debugged to a state that is typical of software immediately prior to unit testing. The software was subjected to five different testing methods including: code reading by stepwise abstraction; static data reference analysis; embedded assertions; functional testing with follow-on structural testing; and triple-version voting. Software error data was accumulated for each technique and software faults were identified.

The experimental activity of applying five different fault detection techniques to eight versions of independently-developed software produced the first known software error data directly comparing fault tolerance and fault elimination techniques. Analysis of the data resulted in significant observations on some current proposals concerning the validation of multi-version software. That is, the data does not support the hypotheses that normal validation can be reduced, that testing can proceed in conjunction with operational use of the software on the basis that the multiple versions (in this case relatively untested, triple-redundant versions) will be highly effective in tolerating faults, and that multi-version voting is a substitute for functional testing. A surprising result was the disjoint nature of the faults sets detected by each of the test techniques used.

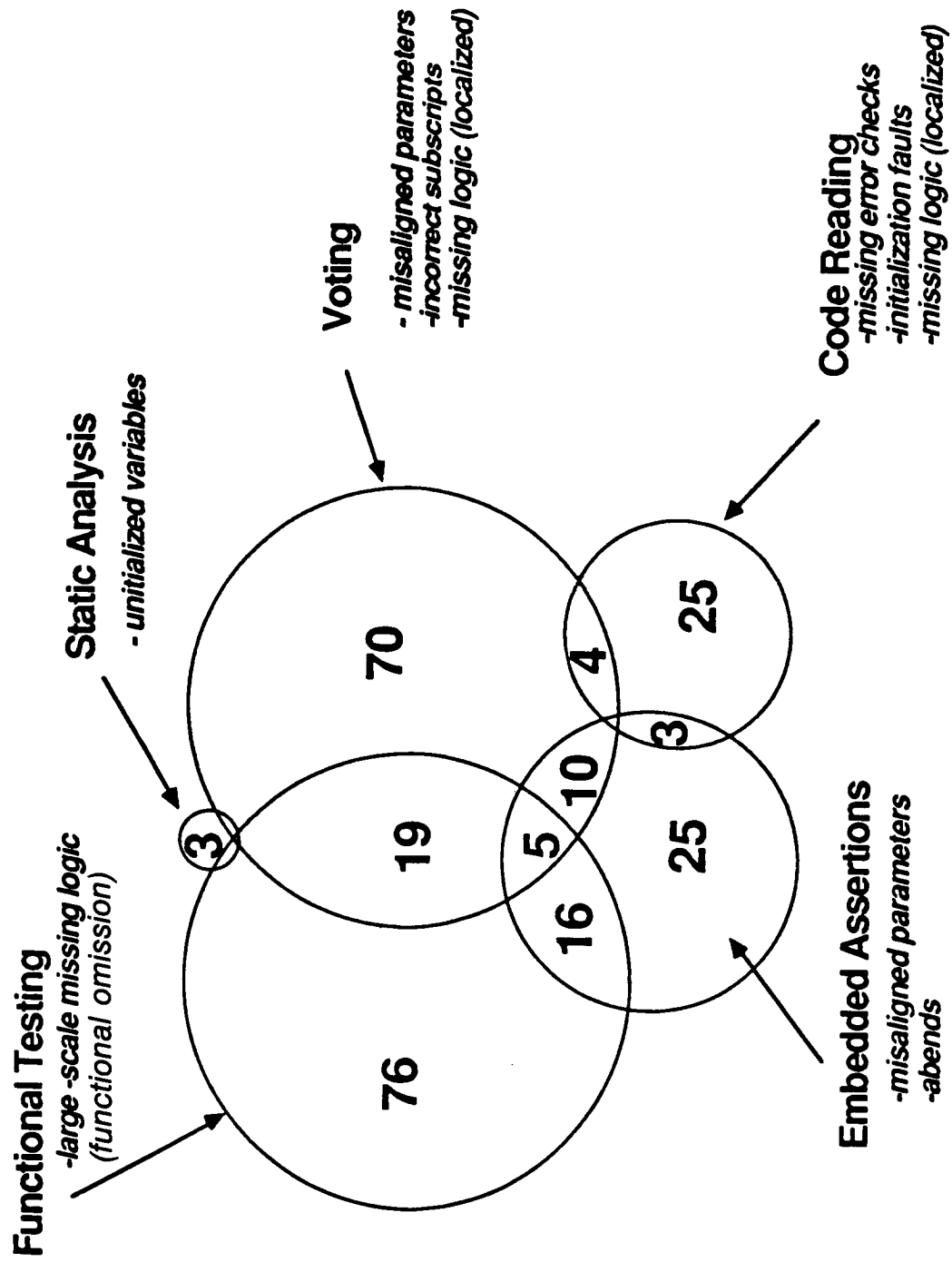
Since current software engineering techniques are generally inadequate for producing highly-reliable software with a high measure of confidence in its validation, fault-tolerant techniques have been proposed and used for critical applications such as the control of aircraft, railroads, and nuclear power plants. However, there is a growing tendency to reduce testing or rely solely on multi-version testing in an effort to reduce software development costs. This research provides the first empirical data comparing fault elimination and fault tolerance and indicates that such a decision may be improper for critical applications. Furthermore, there is evidence that the software testing techniques are complementary and ALL should be used for critical software.

Further experiments are required to confirm or dispute these results. NASA is sponsoring related experiments at other universities.

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FAULT SETS / DETECTION TECHNIQUES

OAS-T



Controls and Guidance - Aeronautics

The overall objective of the Aeronautics Controls and Guidance Program is to provide a validated technology base leading to the development and exploitation of new concepts, analysis and design methodologies, and flight systems for future civil and military aircraft. This will provide increased efficiency, effectiveness, reliability, and safety. The program is organized into generic elements and vehicle-specific elements. The generic elements are Control Theory, Guidance and Display Concepts, and Flight Crucial Systems. Vehicle-specific elements are Generic Hypersonics, Subsonic Transport/Commuter/General Aviation, Rotorcraft, and Fighter/Attack.

Research in the Control Theory element is directed toward the improved flight control analysis and design methodologies for highly integrated, robust flight control designs. These will account for strongly coupled, nonlinear plant dynamics. To develop an understanding of the dynamics of new vehicles, such as VSTOL and High Alpha research vehicles, system and parameter identification methods are being developed. Emerging technologies, such as artificial intelligence, are used in developing new approaches and concepts. Guidance and Display Concepts research involves the development of automation concepts and advanced display media. Flight Crucial Systems research is directed toward the development of design, assessment, and validation methodologies for flight crucial systems. Increasing emphasis will be placed on developing validation methods for real-time, knowledge-based systems in flight crucial applications.

Generic Hypersonics research concentrates on the integration of flight control, propulsion control, sensors and displays. Subsonic Transport research seeks technologies that will provide safer, more efficient civil transport operations in the future National Airspace System. The major thrusts are air-borne sensing, detection and avoidance of wind shear and the development of efficient 4-D guidance and control systems leading to enhanced efficiency, safety, and capacity in the terminal area. Technology developments in automated mission management and goal-directed flight path management leading to automated nap-of-the-earth flight capability are areas of emphasis in the Rotorcraft element. The focus in the Fighter/Attack element is on advanced guidance and control concepts for future super-agile aircraft, development of flight validation techniques for imbedded expert systems, and the development of multidisciplinary design methodology for highly interactive dynamic systems.

The Aeronautical Controls and Guidance Program involves analytical and experimental research performed by in-house, university, and industry personnel. Extensive use of ground-based simulation is a characteristic of the program with selected flight experiments in a variety of aircraft. In the future, more emphasis will be placed on carrying the most promising concepts into flight evaluation and validation programs.

PROGRAM MANAGER: John D. DiBattista
NASA/OAST/RC
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Satellite-Based Navigation

The objective of this research is to evaluate the use of NAVSTAR Global Positioning System (GPS) to support helicopter automated low-altitude aircraft operations and helicopter Nap-of-the-Earth (NOE) flight.

A particularly attractive alternative mechanization of GPS is differential GPS (DGPS), which provides significant improvements in performance when compared to conventional GPS systems. A major attribute of DGPS for NOE helicopter flight is that it does not require direct line-of-sight between the helicopter and ground station for correction signals can be relayed through a satellite link. The additional performance obtained may prove sufficient to support precision hover, autonomous low-altitude flight and instrument approach, and landing operations into areas not currently served by ground-based guidance aids. Offshore explorations, operations into remote and mountainous terrain, and inter/intra city emergency medical rescue are examples of helicopter missions that can be supported by differential GPS.

An inflight evaluation of the DGPS concept using the Civil, coarse acquisition signal (C/A-code) was completed in FY87. The airborne and ground-based components for the concept were developed and successfully flight tested, incorporating real-time differential correction data-linked from the ground station. A reconfigurable navigation algorithm in the airborne computer, was programmed to accept inputs from various onboard sensors to improve the vertical axis performance. During the past year these data have been analyzed. A summary of the vertical axis performance for several system configurations is shown in the figure. The results show that significant improvement in performance can be obtained by including a differential barometric altitude correction (DBARO) with the GPS range correction in the uplinked information.

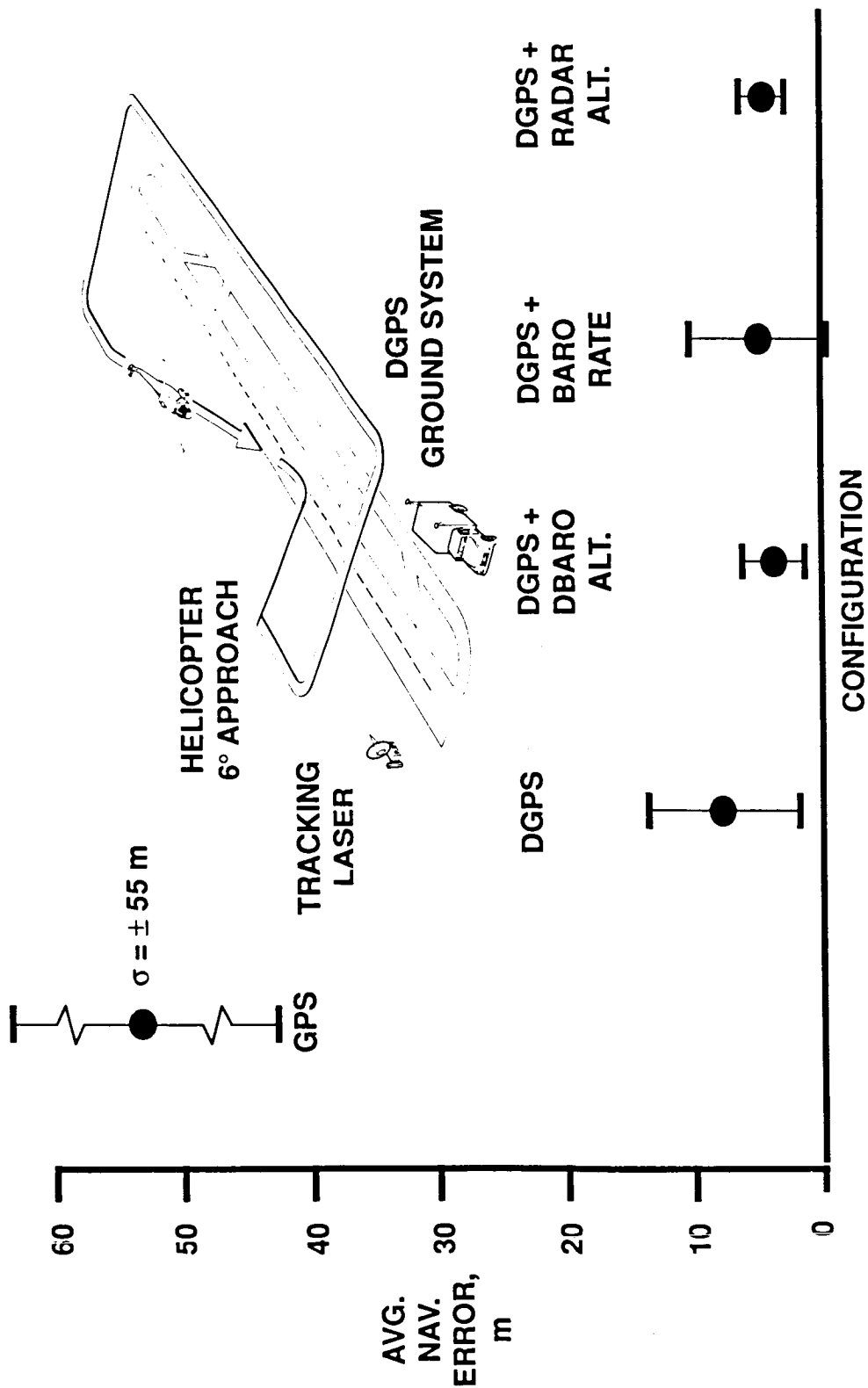
NASA Ames Research Center is utilizing the theoretical and experimental studies conducted under the previous DGPS Helicopter Terminal Approach Program, to evaluate the relative performance of various precision code GPS concepts. An appropriate concept will be selected for development on a NASA flight test vehicle to support the automated NOE test program. Performance of the candidate system will be evaluated through simulation, ground, and inflight testing.

Future plans include: 1) the examination of GPS/INS for precise flight path control during rotorcraft low altitude precision hover and nap-of-the-earth (NOE) flight; 2) the evaluation of Precise Positioning Service differential GPS to support fixed wing aircraft terminal approach operations; and 3) the development of integrity monitoring tools for the differential GPS ground reference system to detect GPS system anomalies and alert users more quickly.

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DIFFERENTIAL GLOBAL POSITIONING SYSTEM (DGPS) C/A CODE VERTICAL AXIS PERFORMANCE

OST



Automated NOE Flight

In high-threat battle areas, military rotorcraft must fly close to the Earth's surface to utilize the surrounding terrain, vegetation, or manmade objects to minimize the risk of being detected. The combination of piloting task and mission functions is extremely taxing for a two piloted crew and potentially prohibitive for a one man crew. Computer aiding with enhanced sensors has been identified as central to alleviating the difficulties in this mission scenario.

The automated NOE (Nap-of-the-Earth) flight program is a cooperative NASA/Army Program aimed at development of technology leading to enhanced low-altitude/NOE flight path management and control through computer aiding. The long-term objective is to work towards achieving a pilot-centered automated NOE flight capability.

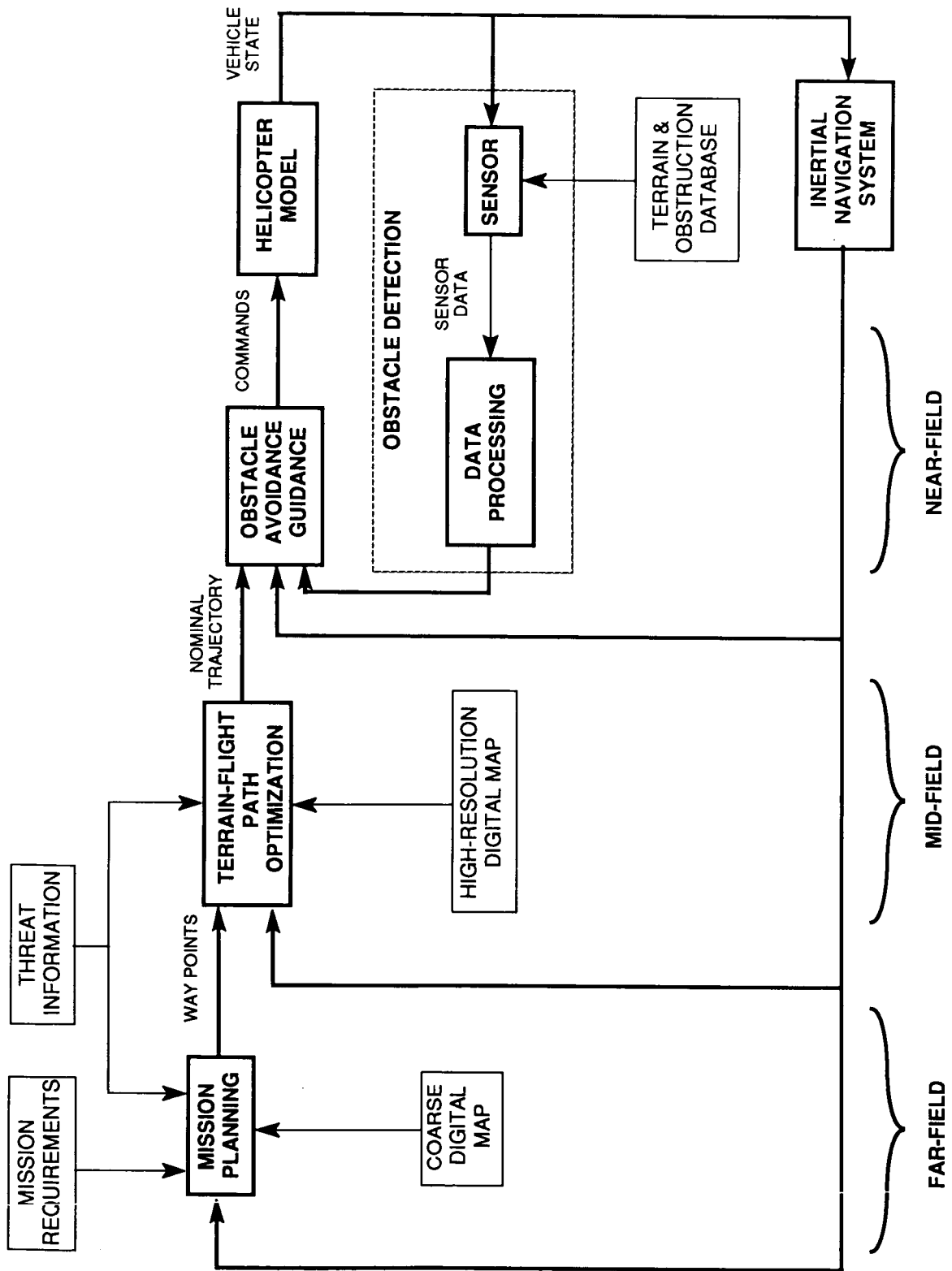
To achieve this goal, the program has decomposed the NOE guidance problem into three levels of functions: far-field, mid-field, and near-field. These three functions can be realized naturally in three feedback loops shown in the attached figure. The outer-most loop, far-field mission planning represents the highest level of decision-making. It aids the pilot on selecting goals and intermediate waypoints to satisfy mission requirements and avoid threats. The coarse route defined by the goals and waypoints is dynamically refined by the mid-field path optimizer. The near-field function deals with obstacle detection and obstacle avoidance.

To address the system issues, a preliminary design for a "return-to-base" autonomous guidance capability has been completed and will be tested in simulation at McDonnell Douglas Helicopter with a follow-on test at Ames. Under a separate effort, a specification for a single axis automated NOE capability that has the potential of early flight validation has been initiated.

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AUTOMATIC NOE GUIDANCE STRUCTURE

0A-S-7



Automated Nap-of-the-Earth Flight: Far-Field Mission Planning

The objectives in far-field mission planning for the automated Nap-of-the-Earth (NOE) program are to define, develop, and demonstrate an effective route planner/replanner for low-altitude/NOE helicopter flight. The planner would support fully autonomous flight of a single-pilot scout/attack helicopter by reducing peak workloads, providing better management of fuel and other resources, minimizing threat exposure, and making real-time changes in the mission plan to meet changing objectives.

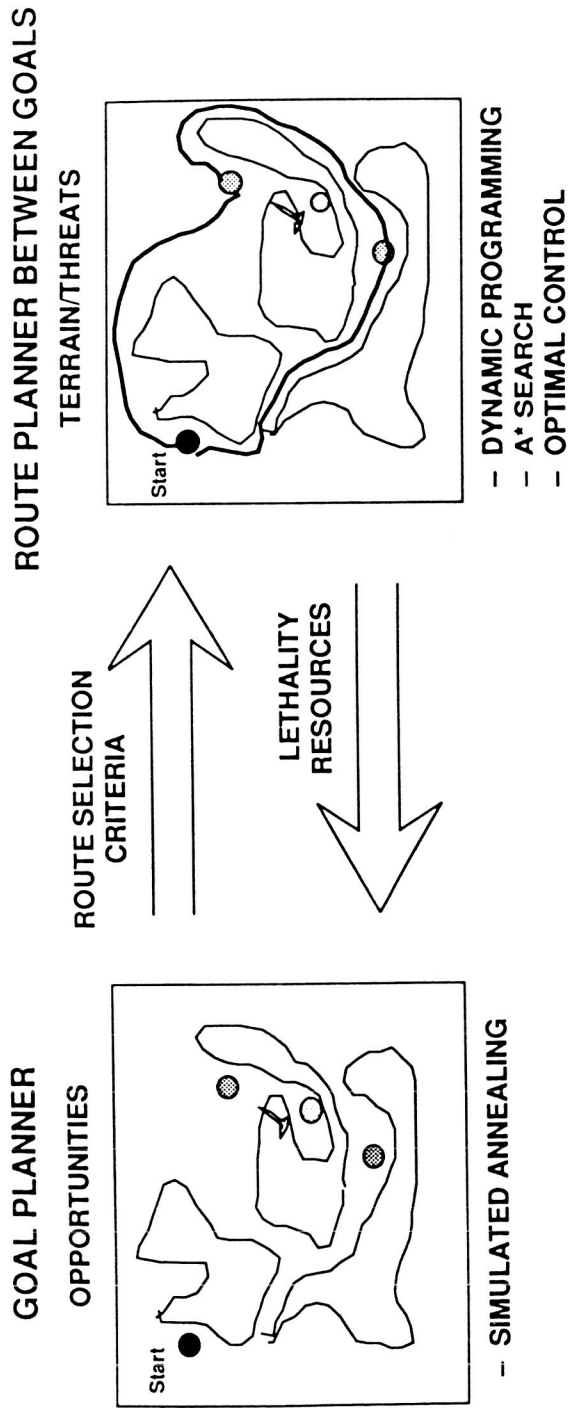
During the past year, an interactive, color graphics display was developed on a SUN 3/160 workstation in the Aircraft Automation Laboratory. This display provides an interactive user interface to control the inputs and operation of the far-field mission planning software. Routes computed by the planners are displayed graphically on a color map of the terrain, color coded to indicate elevation as defined by digital terrain elevation data. Potential threats are displayed in red with the extent of their coverage indicated for the flight altitude of the helicopter. Other data from the planners are displayed numerically and graphically.

In support of the research objectives, three candidate mission route planners are under various stages of development. A Small Business Innovation Research (SBIR) Phase II contract to TAU Corporation provided a mission route planner using a dynamic programming algorithm to produce a globally optimum plan. An early version of this software is operational. This software is being updated to incorporate features developed by TAU during performance of the Phase II contract. A second contract with the Charles Stark Draper Laboratory has developed concepts for a goal planner using a heuristically guided simulated annealing algorithm for goal selection and sequencing. Between goal objectives, this planner uses an A-star search to provide a route and accurate forecasts of fuel, time, and lethality of the path. Phase II of this contract has been initiated to incorporate the algorithms into a complete mission planner. A third route planner based on optimal control theory is being developed under a grant to Georgia Tech. The solution to the two-point boundary value problem is reduced to a one-dimensional search scheme by the use of an adjoint-control transformation resulting in a numerically efficient algorithm to generate an optimal plan.

A test scenario is being developed to examine and compare the three route planners and to integrate the preferred route planner with the goal planner on the SUN 3/160 workstation. The best features of one or more of the three route planners will also be incorporated into a route planner to be used in the Helicopter Operations Planner (under development by the U.S. Army) for use in experiments on the Crew Station Research and Development Facility (CSRDF).

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FAR-FIELD PLANNING



INTEGRATED FOR
EVALUATION ON
SUN 3 WORKSTATION



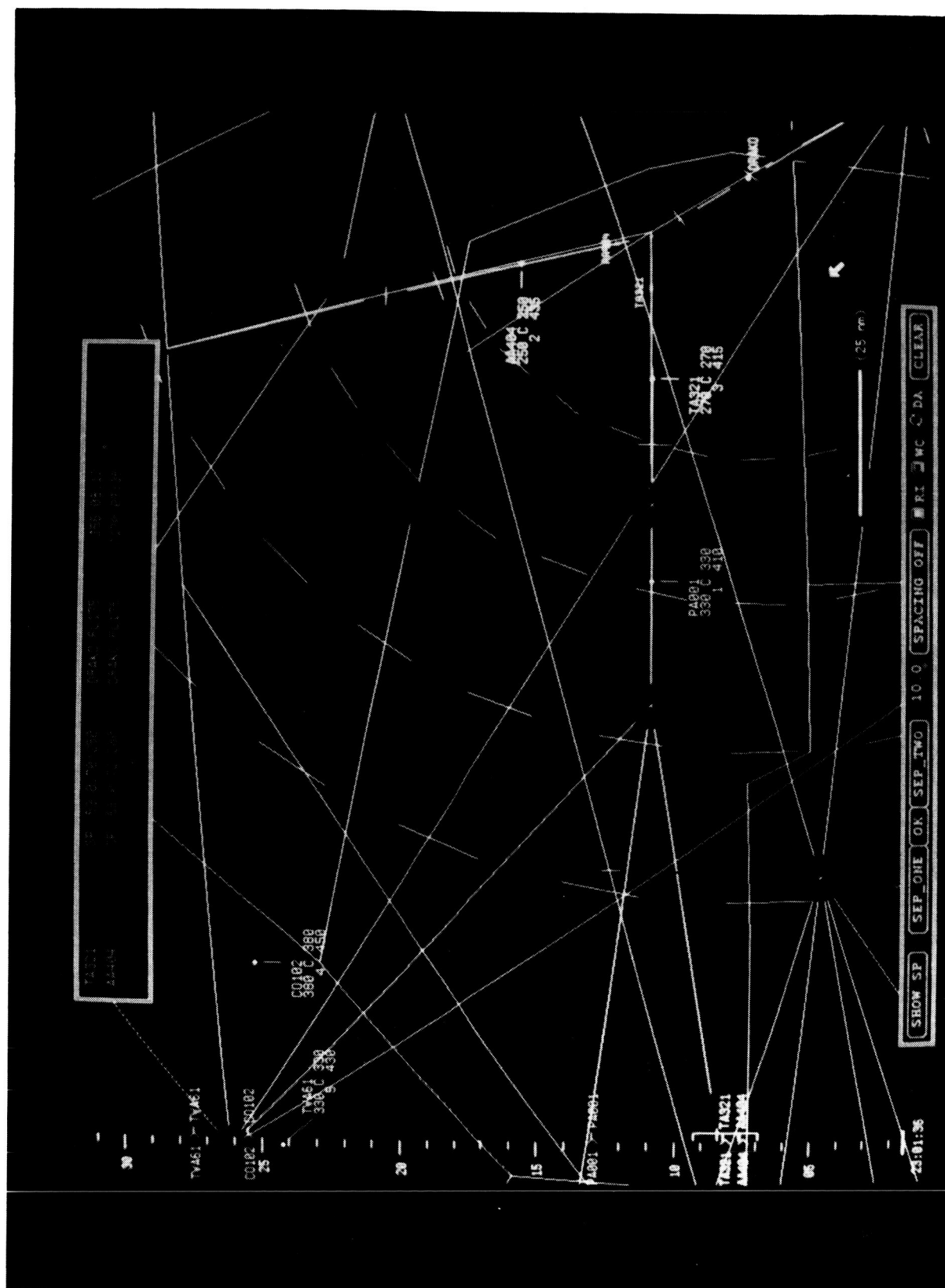
Graphical Interface for Air Traffic Control Automation Tools

NASA Ames Research Center, in cooperation with the Federal Aviation Administration, is conducting research on automation tools for managing terminal area traffic. The objective is to reduce delays, fuel consumption, and controller workload during periods of heavy traffic. A major challenge in the design of automation tools for ATC is the specification of an effective interface between the controller and the complex algorithms needed for manipulating aircraft trajectories in space and time, referred to as 4D guidance. Systems researchers at Ames have recently adapted these concepts to various ground-based air traffic control automation problems. Work is now focused on using interactive computer graphics methods in the design of the controller interface. A graphical interface for a class of automation tools, collectively referred to as Decent Advisor (DA), has been implemented on a Sun Microsystems Workstation. The DA tools are designed to assist a radar controller in managing the flow of arrivals at a feeder gate into the terminal area by generating graphical representations of the spatial and time relationships between aircraft converging at the feeder gate. It also permits the controller to issue commands to the DA tools by manipulating a mouse or trackball. These commands (accessed through a set of on-screen control buttons) provide time-controlled descent clearances and spacing advisories for selected aircraft.

The attached figure is a screen photograph of the controller's display configured for the Denver Center sectors that direct traffic to the Drako feeder gate. The controller has selected DA tools to provide descent information for the two aircraft shown, which are converging on Drako along standard airline routes. He has previously specified ten miles spacing between aircraft arriving at Drako, the point where traffic is handed off to the terminal controller. The appropriate descent clearances to achieve this spacing were calculated and are displayed along with other information in the clearance window at the top of the screen. Thus, XAA404 should start its descent at 54 n.m. from Denver VOR (point labeled TOD for Top of Descent) and fly a Mach 0.72, 300 knot descent profile at idle power. The DA tool predicts that XAA404 will be the first to arrive at Drako and will be followed by XTA321 at a distance of 10.1 n.m. behind the leading aircraft. The spacing distance resulting from these descent and speed clearances is shown by markers at and near Drako. The relative time separation and the arrival time are shown on a time line located on the left. The time line, in one minute increments, displays the time that aircraft are predicted to arrive at Drako within approximately the next 30 minutes. Since current time is at the bottom of the screen and future times toward the top, the time scale, along with predicted aircraft arrival times, moves steadily toward the bottom as time passes. The relative time separation at Drako between the two selected aircraft is seen to be about two minutes. The absolute arrival times can also be read off. They come into play when the controller has to deliver aircraft at times specified by a scheduler or metering system. The vertical bars on the time line indicate the arrival time range available by changing the aircraft speed within the flight envelope. Thus, this graphical interface allows the controller to monitor and control the traffic flow either by distance or time spacing criteria. An extensive controller interactive air traffic control simulation of the DA tools was successfully completed in May 1988. Design is also progressing on an interactive graphics display for a flow control/scheduling advisor system, which will provide optimized arrival times for display on the time line.

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GRAPHICAL INTERFACE FOR ATC AUTOMATION TOOLS



Simulator Evaluation of Controller Tools

The effectiveness of automation aids for air traffic management and the impact of such aids on airline operations was recently evaluated in a combined air traffic control and piloted simulation at Ames Research Center. The initial evaluation concerned the use of the Descent Advisor, an automation aid for arrival traffic management at an Air Route Traffic Control Center (ARTCC).

The objective of this study was to assess the effectiveness of Descent Advisor tools in sequencing and spacing arrival traffic. Under various traffic conditions nine subject controller teams used Descent Advisor tools developed at Ames Research Center to solve a range of traffic management problems: 1) predicting aircraft arrival times; 2) meeting spacing requirements at a feeder fix; 3) resolving spacing conflicts at the fix; 4) merging traffic vectored off route into traffic flow on standard arrival routes; and 5) correcting time errors accumulated by individual aircraft during their descent. In addition, the controllers were asked to evaluate other aids such as the use of multiple colors in the display, a mouse input device for interaction with the descent advisor tool, menu driven controller functions, and a graphical timeline that displayed current traffic time schedules to the fix. The overall response from the subject controllers was strongly favorable. The controllers found the descent advisor to be an effective aid that reduced workload and allowed them to initiate control strategies earlier in the approach than is possible without this tool.

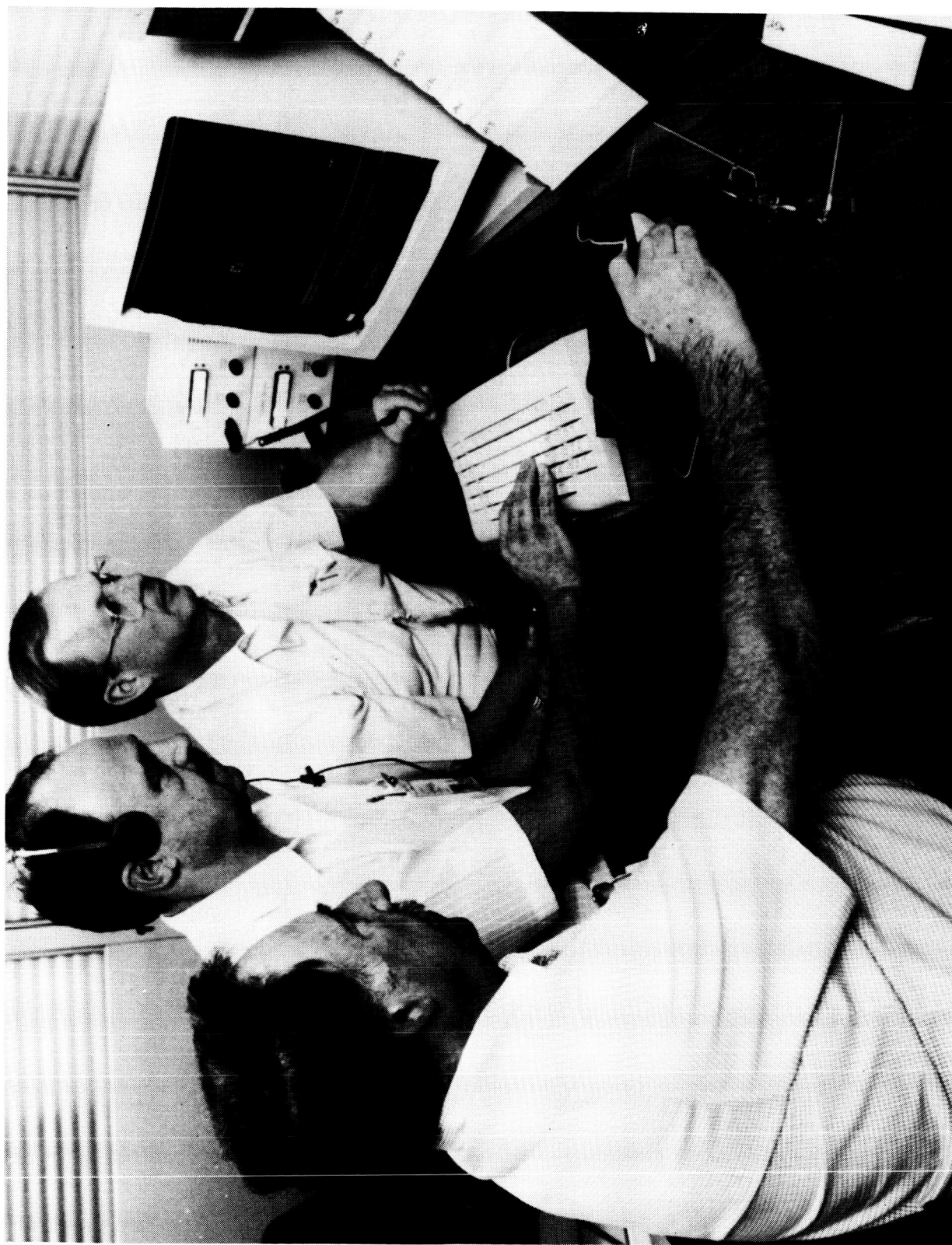
The MVSRRF 727 simulator, which was linked via voice and data link with Advanced Concepts ATC Simulation, provided a realistic measure of the time precision that current airline crews could achieve at a feeder fix by following profile descent advisories issued by controllers using the Descent Advisor automation tool. In addition, the pilots evaluated the acceptability of the advisor assisted descents. Other issues addressed were mid-descent advisories to correct any accumulated error in the descent, the effects of different wind conditions on pilot performance, and procedures for route intercepts during descent. A total of 29 airline crews participated in the simulation executing 180 descents that spanned the entire speed envelope of the 727 aircraft. Preliminary results show most aircraft following the controller's advisory arrived at the feeder fix within 30 sec of their scheduled arrival time. Previous experiments showed that pilots executing pilot-discretionary descents could only be expected to arrive at the fix within 100 sec of their scheduled time which is inadequate for optimal traffic flow. In addition, a mid-descent correction procedure was demonstrated that eliminated virtually all error in arrival time. The pilots were enthusiastic in their support of the concept and could foresee no major operational problems in executing advisory assisted descents.

In a follow-up simulation to be conducted by the end of the year, a terminal radar control (TRACON) position and a flow management position will be included. In addition, LaRC's TSRV 737 4D equipped piloted simulator will be connected to the ATC simulation via transcontinental voice and data links.

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SIMULATOR EVALUATION OF CONTROLLER TOOLS



Vertical Motion Simulator (VMS) Upgrade Project

The vertical motion simulator (VMS) at NASA Ames has been returned to service after extensive upgrade modifications to the motion generation system. The VMS is a large, six degree-of-freedom (DOF) flight simulator used for various aerospace research programs, from fixed-wing to rotorcraft systems. Due to unique performance capabilities needed for rotorcraft simulations, an army-funded project defined and developed a new 4-DOF motion generator with improved performance capabilities. This hydraulically actuated, 4-DOF system has been integrated with the VMS to give a fully independent, 6-DOF motion generation system.

The improved motion capabilities include the addition of an independent longitudinal degree of freedom, and more than doubled the maximum accelerations attainable in the three rotational axes. This new 4-DOF system sits atop the lateral carriage, which sits upon the vertically-moving beam of the VMS. A cone-shaped structure is mounted upon the longitudinal carriage and rotates about the vertical axis to provide yaw. The pitch and roll motions are provided by a gimbal assembly atop the cone structure. All three rotations are driven by hydraulic servo actuators. The simulator cockpit is then mounted on top of the gimbal.

The VMS upgrade project was a major, coordinated effort of approximately 80 man-years, over a two-year period, with much of the design effort and subsystem fabrication accomplished prior to that. The VMS was only taken out of service for one year for hardware installation and integration. During this time, several other refurbishment and upgrade tasks were also accomplished to improve the overall VMS capability.

The new motion system interfaces with the previously existing motion platform, and the system of interchangeable CABS (ICABS). Because of this compatibility, the improved performance capabilities are now available to all Ames and national research programs such as: space shuttle; MV-22, C-17, LHX, and numerous other R & D investigations.

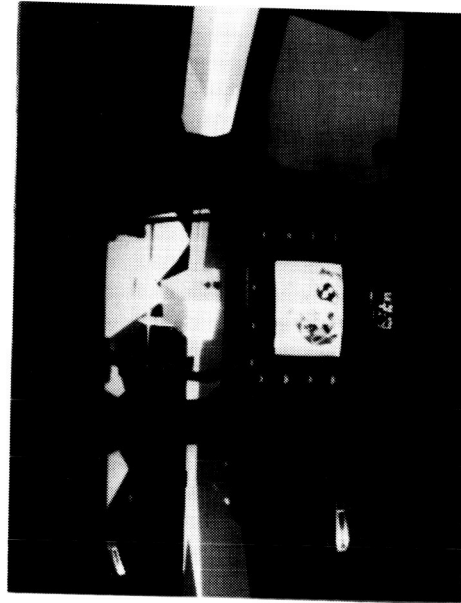
TECHNICAL CONTACT: A.M. Cook, ARC (415) 694-5162

VERTICAL MOTION SIMULATOR

FY 1988 SIMULATIONS

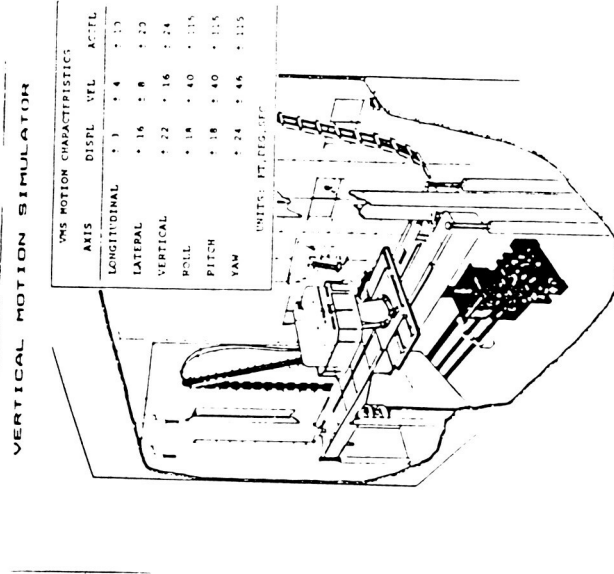
Fixed Base Operation

- Rotorcraft Terrain Following/Terrain Avoidance
- Forward Looking Optical Environment
- Thrust Vectoring Control
- Augusta 109 Evaluation
- Marines V-22 Study
- Voice Activated Controls Simulation



Motion Based Operations

- Space Shuttle Landing/Rollout
- Helicopter Maneuvering Envelope Enhancement



Quantifying Icing Effects on Aircraft Stability and Control Through Flight Test Data

The purpose of the work reported here was to quantify the effect of ice on aircraft stability and control using flight test data, thus allowing for the first time direct comparison of flight test results with analytical predictions and wind tunnel measurements. This work was conducted in support of the National Aircraft Icing Technology Plan.

A flight research program comprised of two thrusts was planned using the NASA deHavilland Twin Otter icing research aircraft. The first thrust was to determine the accuracy with which the aircraft stability and control derivatives could be estimated. To this purpose, 45 maneuvers were performed at the same flight condition to acquire data as a basis for statistical ensemble of stability and control derivative estimates. The second thrust was to determine longitudinal stability and control derivatives for the aircraft both in clean and "artificially" iced conditions. The artificial ice is a strip of plastic molded into a generic ice shape seen in flights and the Lewis icing research tunnel; this constant shape allows for strict repeatability of icing conditions. All flight data were analyzed using the modified stepwise regression algorithm developed in the Aircraft Guidance and Controls Branch and previously reported in NASA TP-1916.

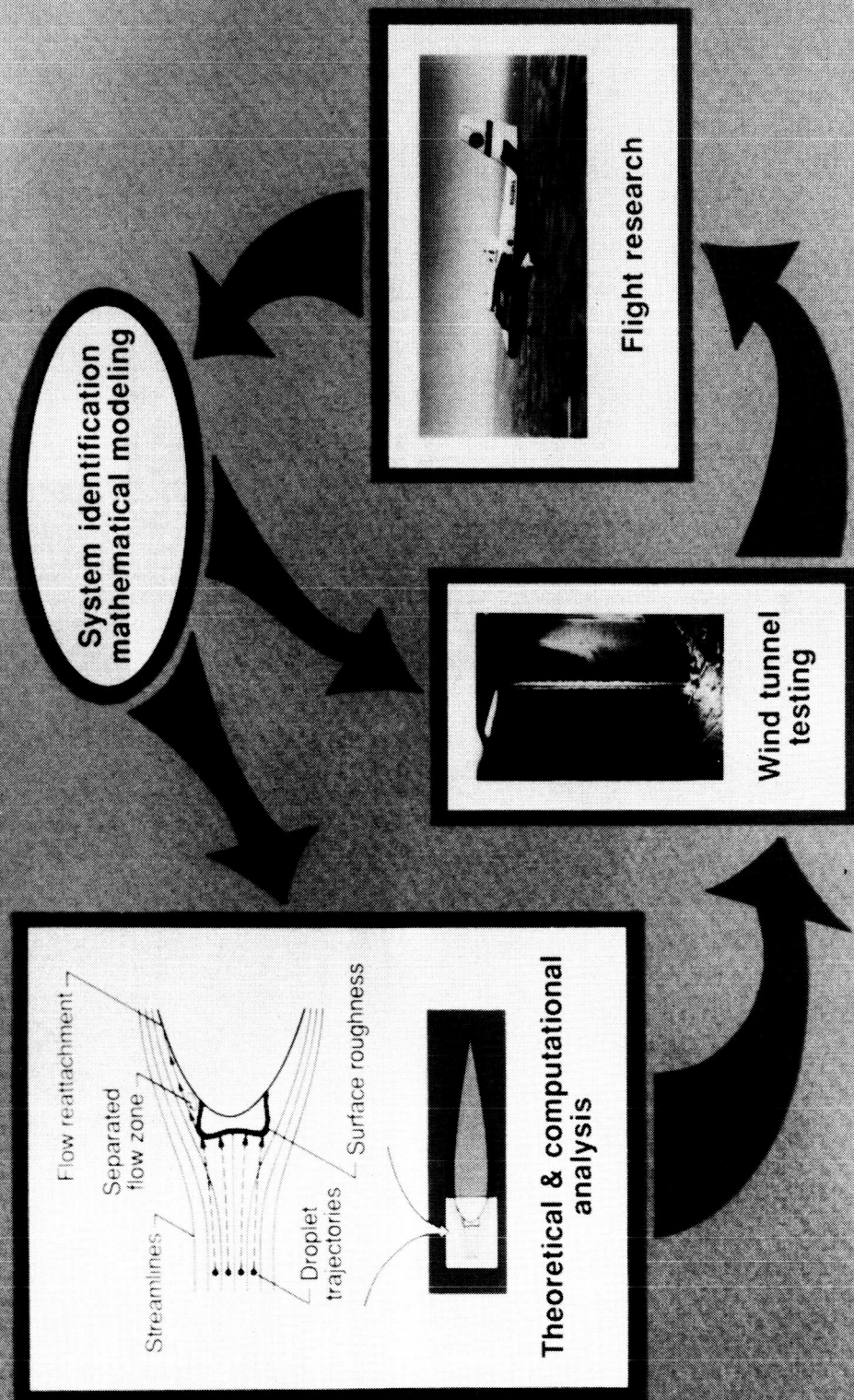
Over 200 maneuvers were planned and performed during four flights in December 1987. The resulting recorded data have now been analyzed as to short period longitudinal stability and control derivatives. A relationship between the ensemble standard deviation and estimated standard deviation of the main derivatives was developed. Significant differences were detected between the derivatives for the iced and uniced airplane.

This analysis indicates that the effect of ice accumulation on this aircraft is quantifiable in the form of stability and control derivatives, which can be directly compared to analytical predictions and wind tunnel results. Such comparison can give confidence bounds to the ground facility measurements resulting in increased efficacy of those measurements for the preliminary design phase of aircraft. Additionally, simulation math models can be upgraded to include realistic aerodynamic models for icing scenarios.

Lewis Research Center will produce analytical and wind tunnel results for comparison with these flight test analyses. The flight test program will continue with flights in natural icing conditions and with extensions to high angle-of-attack approach and landing flight conditions with artificial ice shapes.

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COMPLETING THE MODELING CYCLE IN ICING RESEARCH



Two-Layer, Full Color Thin-Film Electroluminescent (TFEL) Display Patent Awarded

TFEL flat-panel displays have the potential for replacing CRT's in future aircraft and spacecraft because of greater flexibility and reliability, lower weight, space, and power consumption, and graceful degradation characteristics. However, for any flat-panel display technology to replace the CRT, it must have full-color capability. Although full-color TFEL display capability has now been achieved, there is a need to overcome a major shortcoming of low brightness, particularly in the blue phosphor. The research objective was to develop a design for full-color TFEL displays that compensated for the low brightness of the blue phosphor.

Full-color displays require the use and control of the three primary colors: red, green, and blue. The best available red, green, and blue phosphors for TFEL displays differ from each other in maximum brightness. The brightness of the display is limited by the weakest color phosphor (blue). Two leading designs for full-color TFEL displays are: 1) alternating color stripes deposited in the same layer; and 2) a separate phosphor layer for each primary color. An alternate design for fabrication of full-color TFEL displays was conceived. The design, called the Two-Layer, Full-Color TFEL Display, is composed of a one-color, single-layer display superimposed upon a two-color, single-layer display. The size and shape of a picture element (pixel) in the one-color phosphor layer is equivalent to the size and shape of two subpixels (side-by-side) in the two-color layer.

The new display design offers several advantages, one of which is increased display brightness by doubling the active area of the dimmest color phosphor (blue). In the case where the display resolution (pixels/inch) is limited by the minimum width of the electrodes, the new design allows for a 50% greater resolution compared to the single-layer, patterned-phosphor design. The new design also requires roughly one-third fewer interfaces and creates less undesirable capacitance than do present three-layer designs.

The Two-Layer, Full-Color TFEL Display Design has been conceived, completed, and described in a U.S. patent application. NASA has been awarded U.S. Patent No. 4,689,522 for the display design. Further, the display design has been described in a NASA Tech Brief. This patent is one of NASA's most active cases. To date, NASA has received 14 requests for information, from domestic and foreign companies, regarding the design and licensing thereof. Further, Planar Systems, Inc., the world's leading manufacturer of TFEL displays, has begun negotiations with NASA for the purchase of an exclusive licensing agreement.

It is planned that NASA pursue an exclusive licensing agreement with Planar Systems to promote the timely development and application of the new display design and to ensure that an American Company remains at the leading edge.

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CREW STATION TECHNOLOGY

TWO-LAYER, FULL-COLOR TFEL DISPLAY PATENT AWARDED

REAR COLUMN
ELECTRODE

TRANSPARENT
ROW
ELECTRODE

EL BLUE PHOSPHOR

TRANSPARENT FRONT
COLUMN ELECTRODE

GLASS SUBSTRATE

EL GREEN PHOSPHOR

EL RED PHOSPHOR

Reaction-Time Data Shows Effectiveness of Stereo and Pathway Cues in a 3-D Primary Flight Display

Recent advances in liquid crystal (LC) shuttered stereo viewing systems, coupled with high-performance computer graphics, have made possible the generation of integrated, 3-D pictorial primary flight displays having a unique depth cue, called "stereopsis." Use of that technology provided the basis for the present research in the form of a stereo 3-D "real-world" primary flight display having, as primary features, curved "pathway-in-the-sky" and "follow-me" aircraft symbols designed for curved approach-to-landing piloting tasks. The overall goal of this research is to achieve "situation-at-a-glance" pilot awareness; the specific goals of the reported research were to determine the value of "stereopsis" and pathway cues for flight control.

Control reaction times provided a primary assessment criterion in a piloted simulation study designed to determine the effectiveness of stereo and pathway cues. The use of stereo 3-D capability was hypothesized to decrease reaction time in correcting a flight-path offset. Two pathways were used - a monorail and a signpost. Eight Air Force pilots served as subjects. At the start of each trial, pilots were initiated on the nominal flight path. After two seconds, they were offset to one of eight positions. As soon as the pilots detected an offset, they were required to make the initial stick input to fly toward the nominal flight path. They were instructed to respond as quickly as possible, but that accuracy was of paramount importance. After their initial input, the trial was ended.

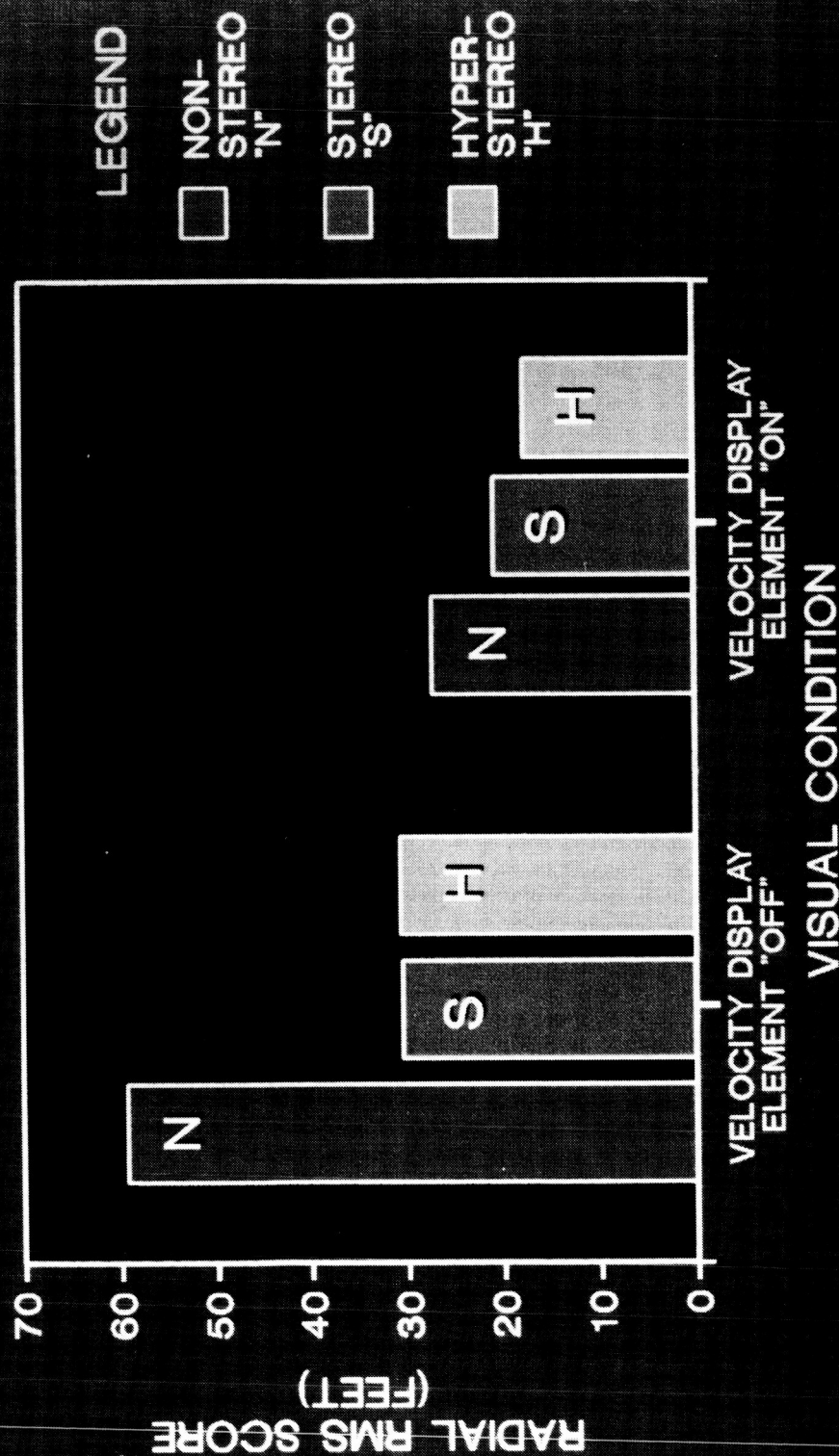
Pilots responded more quickly when the display was presented in stereo 3-D than when a monocular (i.e., non-stereo) display was presented. The average reaction time was 690 msec for stereo display vs. 725 msec for non-stereo. That difference is statistically significant ($p=.000$). The responses to the signpost pathway were significantly faster ($p=.000$) than were the responses to the monorail pathway (665 msec vs. 750 msec, respectively). Also, the stereopsis by pathway interaction was significant ($p=.005$). Further, the pilots were able to respond faster when the "follow-me" aircraft was displayed than when it was not (695 msec vs. 720 msec, $p=.002$).

This study quantitatively shows, for the first time, the effectiveness of stereo 3-D cues in a computer-generated, pictorial primary flight display. Pilots responded faster with the stereo 3-D display, indicating improved awareness with stereo. The significant interaction of stereopsis with pathway also has implications for designers of non-stereo pictorial displays. The pilots clearly responded faster with the signpost pathway. The difference in reaction times was much greater when the non-stereo display was used instead of stereo 3-D. This means that it is potentially even more critical for designers of non-stereo pictorial displays to carefully evaluate the effectiveness of their pathway cues.

A follow-on study is planned to determine whether the effectiveness of stereo, signpost pathway, and "follow-me" aircraft cues carry-over from the static trials used in the present study to dynamic flight situations. In this study, the pilots will fly the simulator to rejoin the flight path after the offset.

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EFFECTIVENESS OF STEREOPSIS AND VELOCITY DISPLAY ELEMENT IN ROTORCRAFT PRECISION HOVER



Validation of the Semi-Markov Unreliability Range Evaluator (SURE)

As part of the validation of the SURE reliability analysis tool the research objective was to analyze the underlying bounding theory and test the implementation of the theory in the program to demonstrate efficacy.

Since manual derivation of the exact reliability of realistic fault-tolerant systems is impracticable, the automated tool, SURE, was developed to give an upper and lower bound on system unreliability for a semi-Markov model of a system. Since SURE bounds are algebraic in form, they are relatively simple to compute. However, before such a tool could be used for evaluation, the tool itself should be validated and no formal methodology for validating a reliability analysis tool exists. The goal in this program was to show that SURE's bounds enveloped the exact unreliability for any given semi-Markov model of a system. Although the mathematical bounds implemented in SURE have been rigorously proven, extensive testing is needed to ensure that the theoretical bounds are correctly implemented in the program. The next phase in the validation effort concentrated on three main tasks: 1) comparison of SURE's bounds to exact analytic solutions for simple semi-Markov models; 2) comparison of SURE's bounds with unreliability estimates made by other reliability analysis tools for more complex models where analytic derivation of the exact solution is infeasible; and 3) analysis of the relative error in the bounds for models that are pure death processes and renewal processes.

A total of 35 models and over 250 test cases were used to test the accuracy of SURE's bounds. In general, SURE's upper bound provided a very good estimate of the unreliability. Although there were cases where the bounds separated, most of these cases had either fast fault-arrival rates or slow fault-recovery rates, which are not considered typical of a fault-tolerant computer system. Analysis of the mathematical bounds also showed that the error in the bounds increases as the model parameters stray from those regions typical of fault-tolerant systems. Analysis of the relative error for models with renewal revealed that the bounds converge rapidly for renewal models representing transient faults.

This effort represents the first independent, comprehensive evaluation of SURE. Both the analysis of the mathematics and testing of the program with numerous models fulfill integral requirements in the validation of a reliability analysis tool. Although all aspects of SURE have not yet been tested, the results of this testing give confidence that SURE's bounds indeed envelope the unreliability of any semi-Markov model of a system.

Future plans include production of documentation of the results of the validation effort to provide users with confidence in SURE. Also, in-house testing of the program in conjunction with testing at a number of beta test sites in further support of the validation will be continued.

TECHNICAL CONTACT: Kelly J. Dotson, LaRC, (804) 864-1000

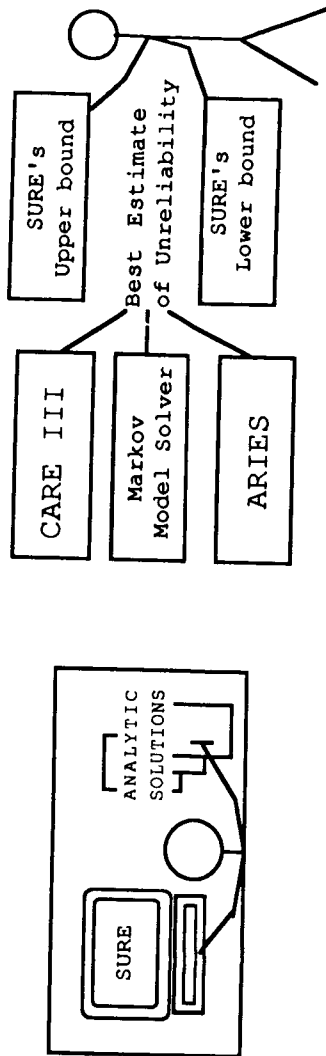
VALIDATION OF THE SURE PROGRAM

OAS-T

Rigorous Proof of
Theoretical Bounds



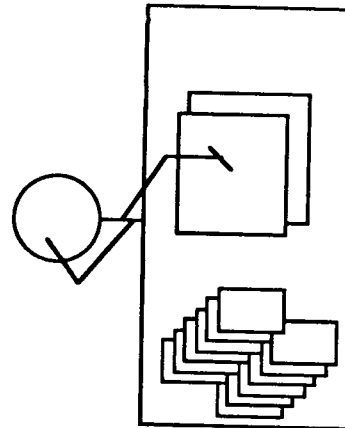
Comparison of SURE
to Other Techniques
for Computing Reliability



Comparison to
Analytic Solutions
(15 models, 150+ test cases)

Comparison to Other
Reliability Analysis Tools
(20 models, 100+ test cases)

Analysis of Mathematical
Bounds to Determine Regions
Where the Bounds Separate



Upset Assessment Methodology

The objective of this research was to develop a method to predict the effects of lightning and other electromagnetic disturbances on aircraft and spacecraft digital systems.

It has been impractical to model a complete digital system at the level of detail necessary (transistor level) for accurate transient analysis. Therefore this problem was circumvented by using transistor-level modeling in circuitry close to the disturbance where activity is complex. Gate-level modeling was used to trace the effects throughout the remainder of the digital system. The System for Circuit Evaluation and Prediction of Transient Radiation Effects (SCEPTRE) Program was used to compute the transistor-level effects. The SCEPTRE results were then manually entered into the General Simulation Program (GSP) to complete the simulation at the logic level. This method has been demonstrated to give useful results for small digital systems but it is too slow and cumbersome for the analysis of larger, more useful digital systems. A dual-mode, transistor-level and gate-level simulator with pre- and post-processors has been assembled to efficiently simulate the action of electrical transients on larger digital systems.

A new upset assessment methodology has been developed. It employs the Splice experimental multimode simulator from University of California-Berkeley; a system description translator developed at University of Illinois, Urbana-Champaign, under NASA LaRC grant; and a post processor developed at LaRC. An Electronic Engine Controller (EEC) has been implemented using a description of an EEC furnished by the Hamilton Standard Division of United Technology, Incorporated. Preliminary runs of the EEC simulation model show that it successfully executes the controller's application software.

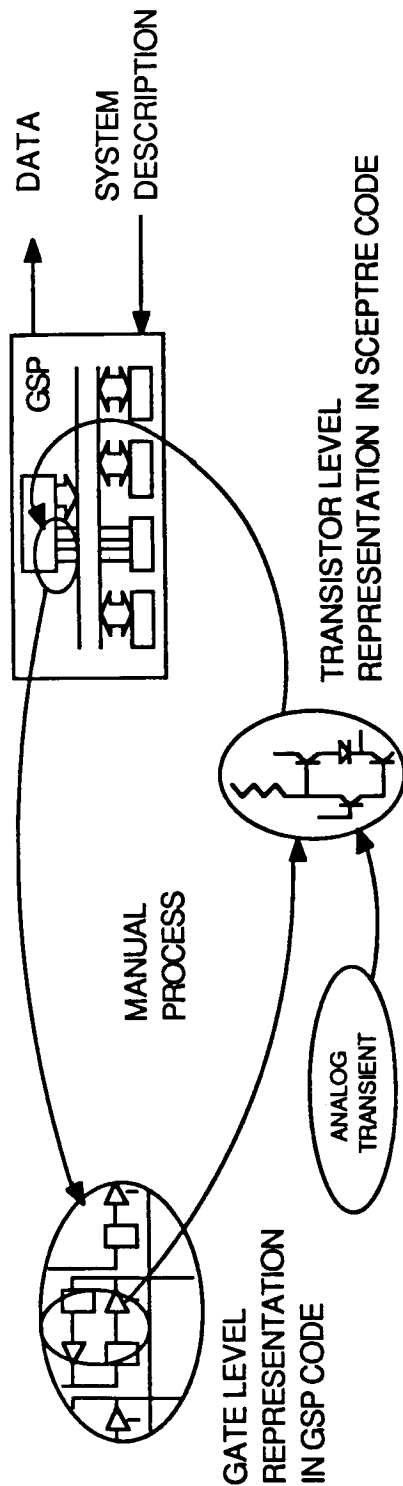
The automation of the analytical assessment method provides a significant increase in capability to create a broad database from simulation for comparison with data obtained from hardware experiments. A meaningful statistical comparison was not previously feasible due to the limited number of simulation runs.

In the future, this methodology will be validated by comparing the results of a simulated EEC with the response from an actual controller. Also, plans are to model a dual redundant controller and evaluate the built-in capabilities to resist and recover from external disturbances.

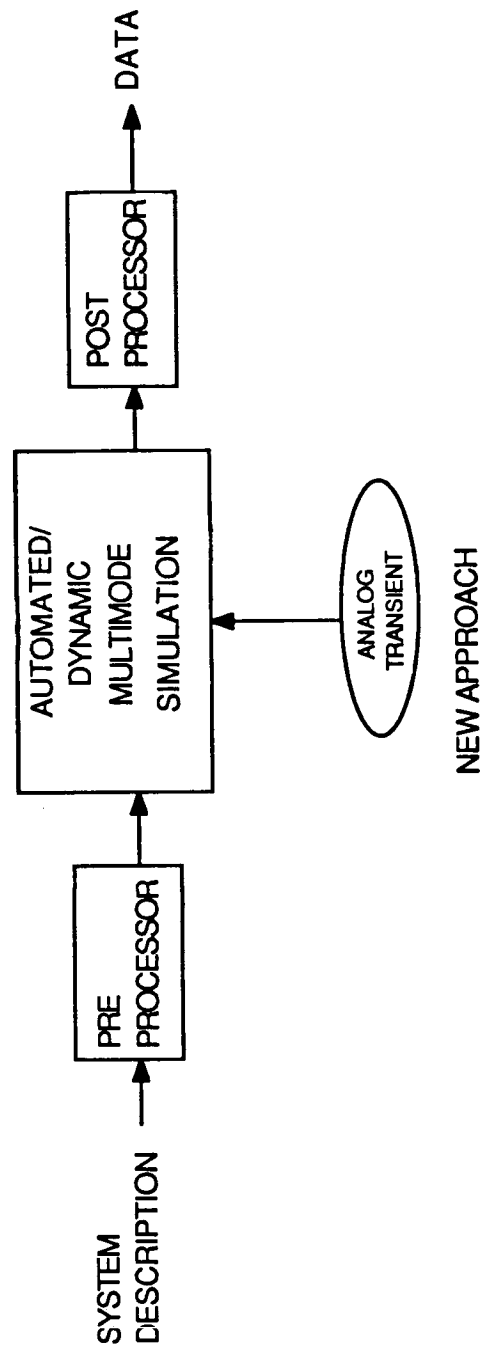
TECHNICAL CONTACT: Victor A. Carreno, LaRC (804) 864-6184

UPSET ASSESSMENT METHODOLOGY

CAST



PREVIOUS APPROACH



Performance Assessment of the Fault Tolerant Processor (FTP)

Quantification of the performance of the Fault Tolerant Processor (FTP) was the objective of this research.

For the FTP, performance depends on the speed of the hardware, the efficiency of the operating system, and the time required to execute application tasks. The degradation of performance due to the hardware response times was found by measuring and recording the significant delays (bottlenecks) in data flow using a logic analyzer. To measure the performance penalty caused by the operating system, the Data Acquisition System (DAS) was used. DAS monitors and records the values of selected global variables, declared in the FTP operating system software, at a rate of 25 Hz. Thus, by inserting clock-read instructions into the operating system both before and after specific functions occurred (i.e., scheduling, synchronization, and fault coverage routines) and assigning them to global variables, the delays attributable to operating system tasks were found. Allowing for the operating system overhead in the total available time, a representative instruction mix, the Digital Avionics Instruction Set (DAIS), was fit into the remaining time and the throughput calculated based on the number of instructions executed per second.

Many of the previously unquantified performance and functional parameters of the FTP were characterized at each level of the system. At the hardware level, bottlenecks in data flow were found, which include a memory access delay of 250 ns, an I/O access delay of 3 μ s, and a delay in performing consistency checks on the data of 8 μ s. The operating system overhead used 13.6% of the total throughput of the system, 10.4% attributable to the redundancy management software. At the application level, following implementation of a workload model, a best-case performance of 318 KIPS was calculated for the fault-free state.

It is apparent that the FTP, despite the high reliability claims of a quadruply redundant architecture, is, at best, marginally adequate to meet the performance requirements of advanced flight control systems. Specifically, these experiments reveal that: 1) because of the bottlenecks in accessing memory, performing I/O operations and voting redundant data, applications which require extensive usage of these resources will do so at a much slower rate (<318 KIPS); and 2) the operating system overhead is minimized by executing most of the fault coverage routines at low priority. Thus, the delay in covering many types of faults will increase if the system is heavily loaded.

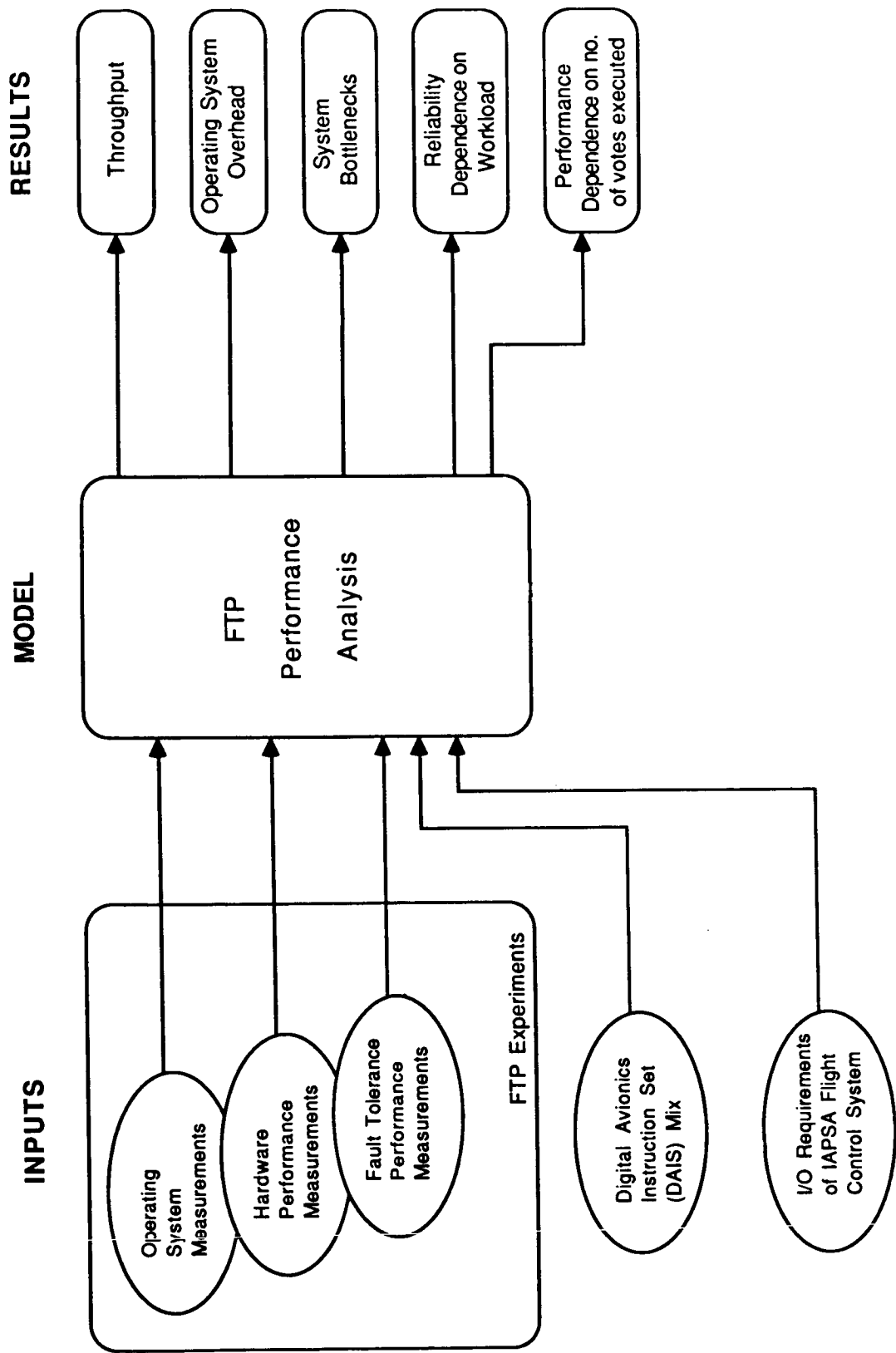
In the future a complete characterization of the system will be done, repeating these experiments in a faulted state, to quantify the effect of failures on performance. Also, the specific relationship between the reliability of the system and the load placed on the system will be found. Finally, system enhancements will be suggested to optimize system performance.

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FTP PERFORMANCE ASSESSMENT EXPERIMENT

OASST



"Timer" Simulation and Flight Evaluations

The objective is to define, develop, and evaluate evolutionary ATC concepts employing automation aids that would improve the capacity, reliability, and economy of extended terminal flow operations (en route approach, transition, and terminal flight to the runway) when used with projected ground and avionic hardware. The evolutionary system must accommodate today's as well as projected advanced-technology aircraft.

A time-based concept called TIMER (Traffic Intelligence for the Management of Efficient Runway-scheduling) has been developed, which integrates en route flow control, runway scheduling, and spacing, together with fuel saving flight-idle descents to both fully utilize runway capacity and improve fleet efficiency. TIMER was designed for evolutionary integration into today's manual, voice-linked ATC system by generating suggested speed and vector instructions to assist the controller in delivering non-4-D aircraft to their scheduled times. TIMER was incorporated into the Terminal Area Air Traffic Model (TAATM) for fast-time evaluation. A real-time version was developed and linked with a transport cockpit simulation for crew-in-the-loop, conventional aircraft performance measurement. Verification flight tests were conducted with the ATOPS B737 flying under TIMER control at Wallops.

Based on results from a fast-time parametric sensitivity evaluation of the Timer Concept to determine the effects of key system variables, real-time simulation tests, using airline crews, were conducted with the full-workload DC-9 cockpit simulator, and a certified ATC controller. Test results have demonstrated that conventional non-4-D aircraft can be delivered to the runway with an interarrival error standard deviation in the region of 10 to 15 sec. As the accompanying figure shows, this translates to about an 18% arrival capacity improvement over the 26 sec. achieved in present practice. Flight tests at Wallops Island using the forward cockpit of the ATOPS B737 flying under real-time TIMER control have verified these findings.

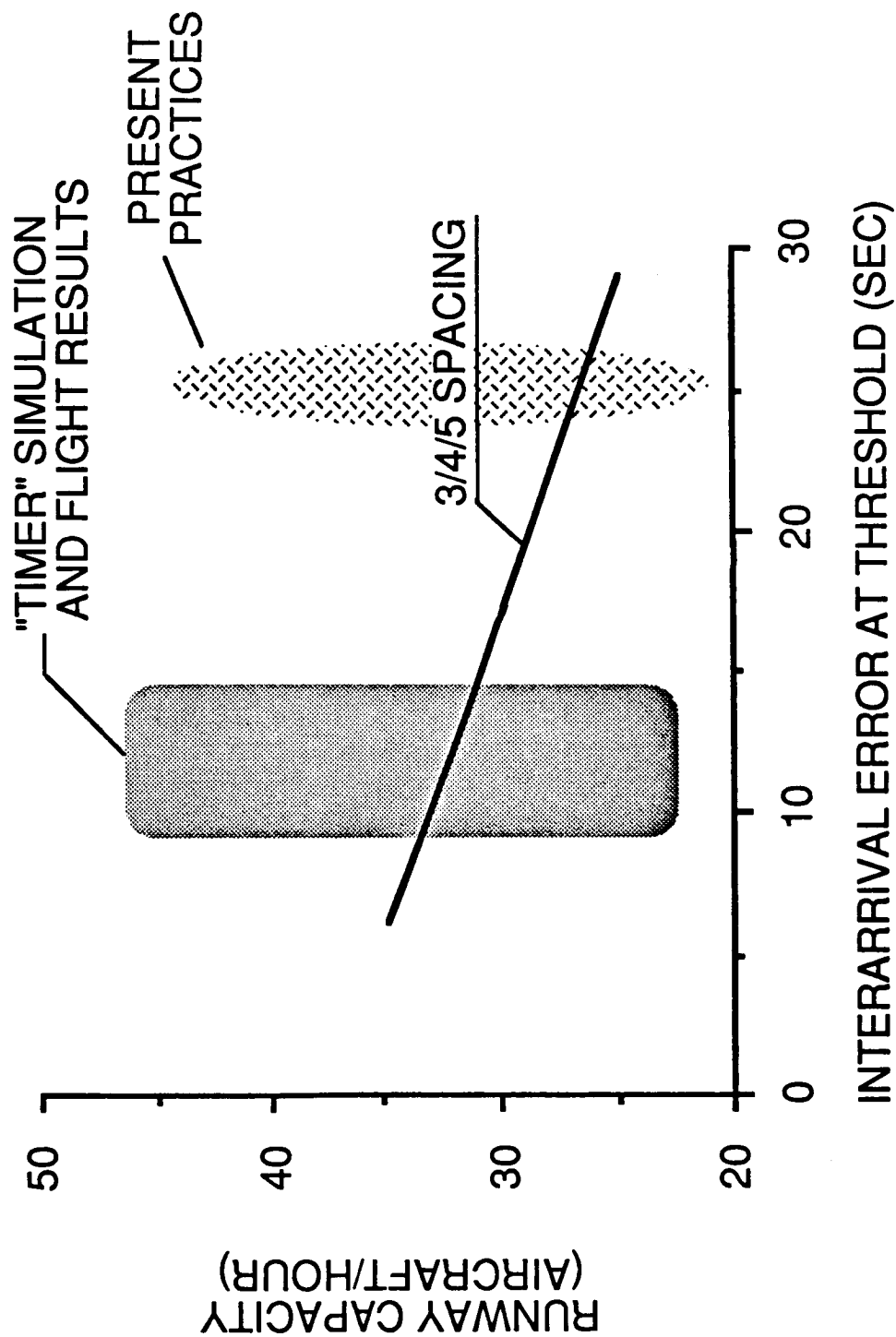
The simulator and flight test results demonstrate that a significant part of the capacity benefits possible from an extended-terminal time-based ATC flow-control system can be realized before the airline fleet is equipped with 4-D Flight Management Systems.

Future real-time simulations will explore ATC controller/TIMER interface issues and display options, which are critical not only to system performance but also to operational acceptance.

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EFFECT ON INTERARRIVAL ERROR ON RUNWAY CAPACITY (IFR)

CAST



Control Mode Panel Logic

The objective of this research is to develop, evaluate, and demonstrate applications of artificial intelligence (AI) programming tools and methods for aircraft control law design (AI-aided design) and for implementation of logic functions (embedded AI) associated with advanced aircraft guidance and control systems (GCS). The research will evaluate the potential of these methods to reduce the cost and time of GCS design and software development, to simplify the implementation of complex GCS, and to increase the functional capability and reliability of the GCS.

AI programming tools and methods are being investigated and applied at LaRC for implementation of aircraft advanced guidance and control functions under the Knowledge-Based Controls program. The AI implementations will be evaluated with advanced computer workstations, simulations, and, for some, flight tests for proof of concept. An initial project of this research was to implement and flight test the complex logic associated with the control mode panel (CMP) on the Transport Operating Systems Research Vehicle (TSRV), a modified Boeing 737 aircraft, operated by the Advanced Transport Operating Systems (ATOPS) program at LaRC. The CMP permits the pilot to select various control modes and to set desired flight parameters in the fly-by-wire control system of the research aircraft.

The CMP logic was successfully implemented with the symbolic processing language LISP using typical AI programming techniques and was proven to perform properly. By taking advantage of the AI software structure, a message feedback fail-mode advisor was developed and added to the CMP logic to aid the pilot in operating the panel. The LISP code was then translated into the high-level procedural language C for use and test in the flight computers of the ATOPS research aircraft and was successfully flight tested.

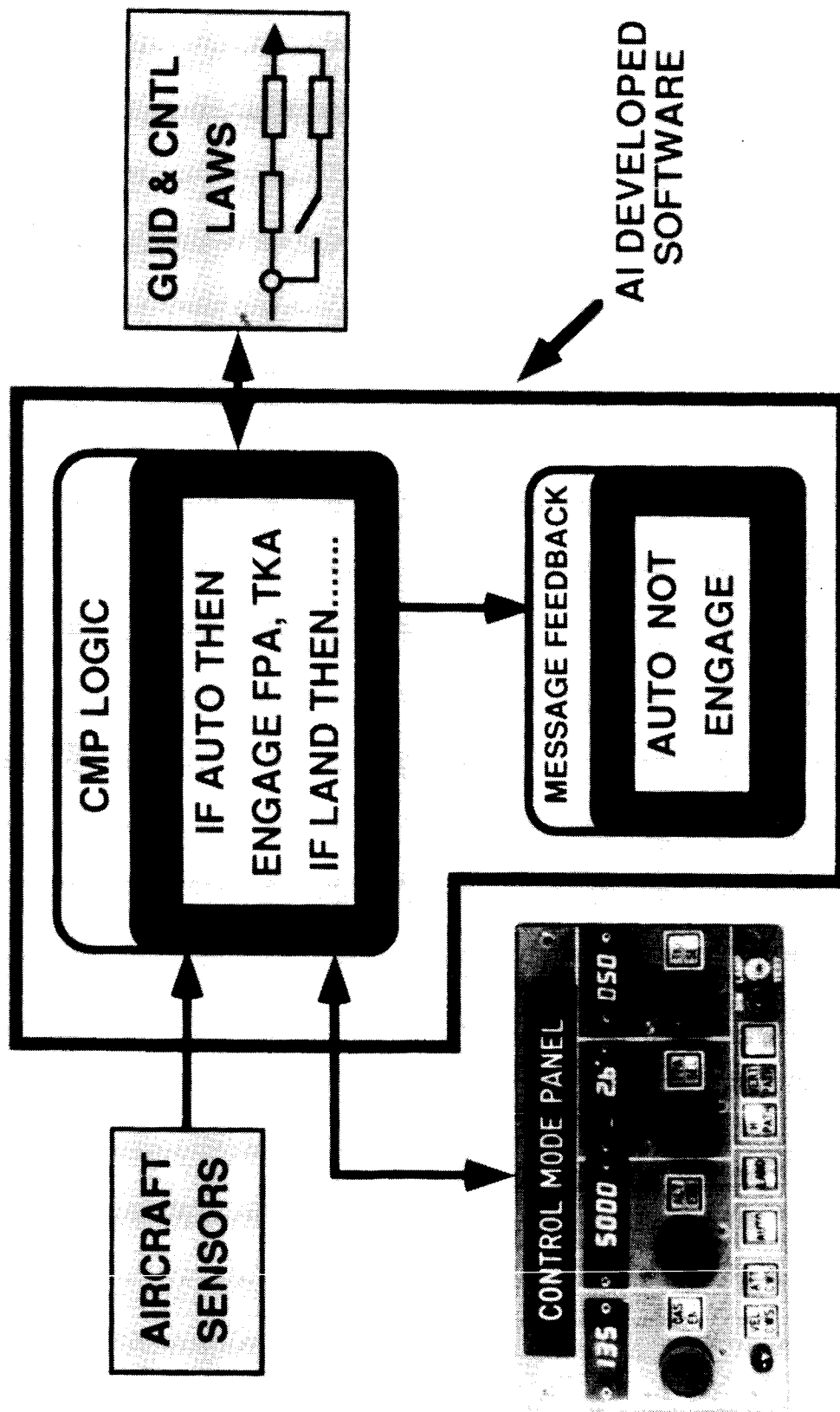
As a result of the introduction of digital computers, electronic cockpits, and fly-by-wire control, GCS design and software development for the modern transport aircraft has become a major cost factor. Moreover, the extent and logical complexity of GCS software is expected to increase as digital computer capabilities increase and more autonomous functions are implemented. It is estimated that the modern GCS software is now at least 80% logic. Software modifications with currently used software tools can be difficult and risky (inadvertent changes to existing code). To date, this research project has shown that the potential exists for an order of magnitude reduction in the software development time for complex logical functions. Additionally, the development and incorporation of the message feedback advisor demonstrated that modifications to existing AI software are significantly easier to program than conventional methods. Another open question was answered when the methods employed also proved to be satisfactory for real-time operation. The CMP logic system became the first real-time flight crucial system, based on AI principles, to be tested on a commercial type aircraft for proof of concept.

AI programming techniques will be applied to the implementation of the entire TSRV guidance and control system including control mode panel logic, the control laws, the control law logic, and navigation and guidance functions.

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KNOWLEDGE-BASED CONTROLS

AI-BASED CONTROL MODE PANEL LOGIC SYSTEM



Microburst/Clutter/Doppler Radar Simulation Program

The objective of this research was to develop airborne Doppler radar technology for the detection of low-altitude microburst wind shear, and assess its capabilities and limitations as a forward-looking sensor for detecting wind shear during aircraft landing and takeoff.

The approach was to develop a microburst/clutter/radar simulation program which accurately calculates the expected output of an airborne pulse Doppler radar system viewing a low-level microburst along or near the approach path of the aircraft with a background clutter environment.

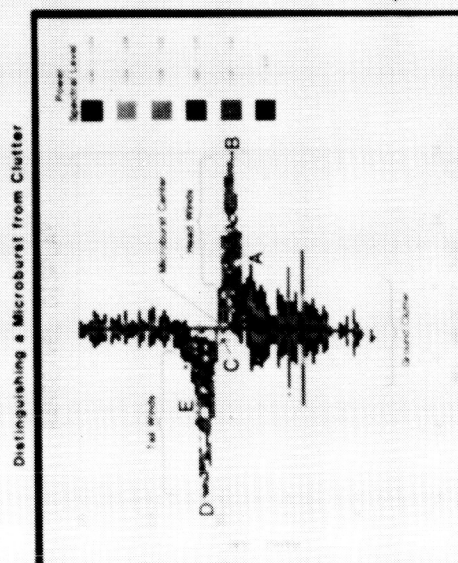
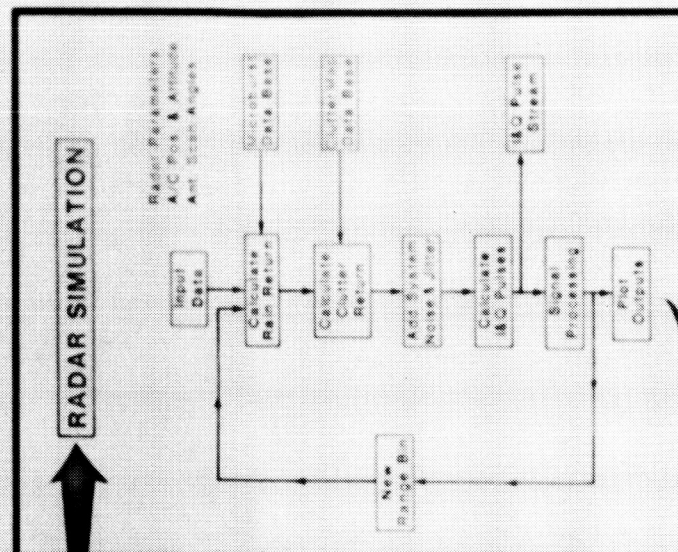
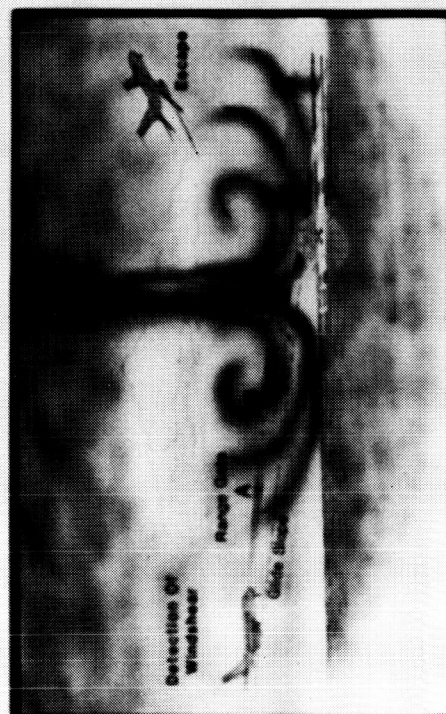
A comprehensive computer program has been developed, which simulates the operation of a Doppler radar located in an aircraft approaching a runway, sensing signal returns from a microburst and an airport clutter environment. The program incorporates windfield and reflectivity data bases derived from a numerical wind shear model, clutter maps derived from Synthetic Aperture Radar backscatter data, and various radar configurations, and signal processing concepts. A preliminary performance assessment study of a radar concept sensing both "wet" and "dry" microbursts has been conducted using this simulation program. (Bracalente, E.M.; Britt, C.L.; and Jones, W.R.: ALAA 88-4657-CP, ALAA Meeting on Sensor & Measurements Technology, Atlanta, GA., September 1988).

This comprehensive simulation program will provide an analytical tool for accurately evaluating the performance of various airborne radar concepts and signal processing techniques for detecting microburst wind shear during aircraft landing or takeoff.

Improvements in the program will be made by incorporating more sophisticated signal processing techniques, models to represent moving ground clutter, improved displays of simulated output data for evaluating performance, and methods for evaluating true, nuisance, and missed-hazard alarms. A full range of microburst/clutter environments will be investigated, and extensive tradeoff and optimization studies conducted.

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RADAR SIMULATION & DISPLAY



Automated Flight Test Management System (ATMS)

ATMS is a computer system that helps flight test engineers in planning and monitoring flight tests. It consists of a Texas Instruments Explorer LX Symbolic Computer Ethernetted to a MASSCOMP general purpose workstation and the NASA Ames-Dryden Simulation Facility. The system aids FTE's in flight test planning, block planning, program planning, flight monitoring, real-time replanning for contingencies and anomalies. It provides automatic control (through the NASA Ames-Dryden Remotely Augmented Vehicle (RAV) System) of a flight test including standard flight maneuvers and transitions between maneuvers as an option to manual control. It features the integration of knowledge-based and expert systems for planning and monitoring functions, six DOF simulations of the flight vehicle in question and algorithmic flight test trajectory controllers to provide outer loop maneuver control of either a simulation or the real airplane. It has been successfully demonstrated in real-time simulation at NASA Ames-Dryden for the HIDEC F-15 airplane in a limited flight test scenario. The ultimate application is the flight testing of Hypersonic Research Vehicles.

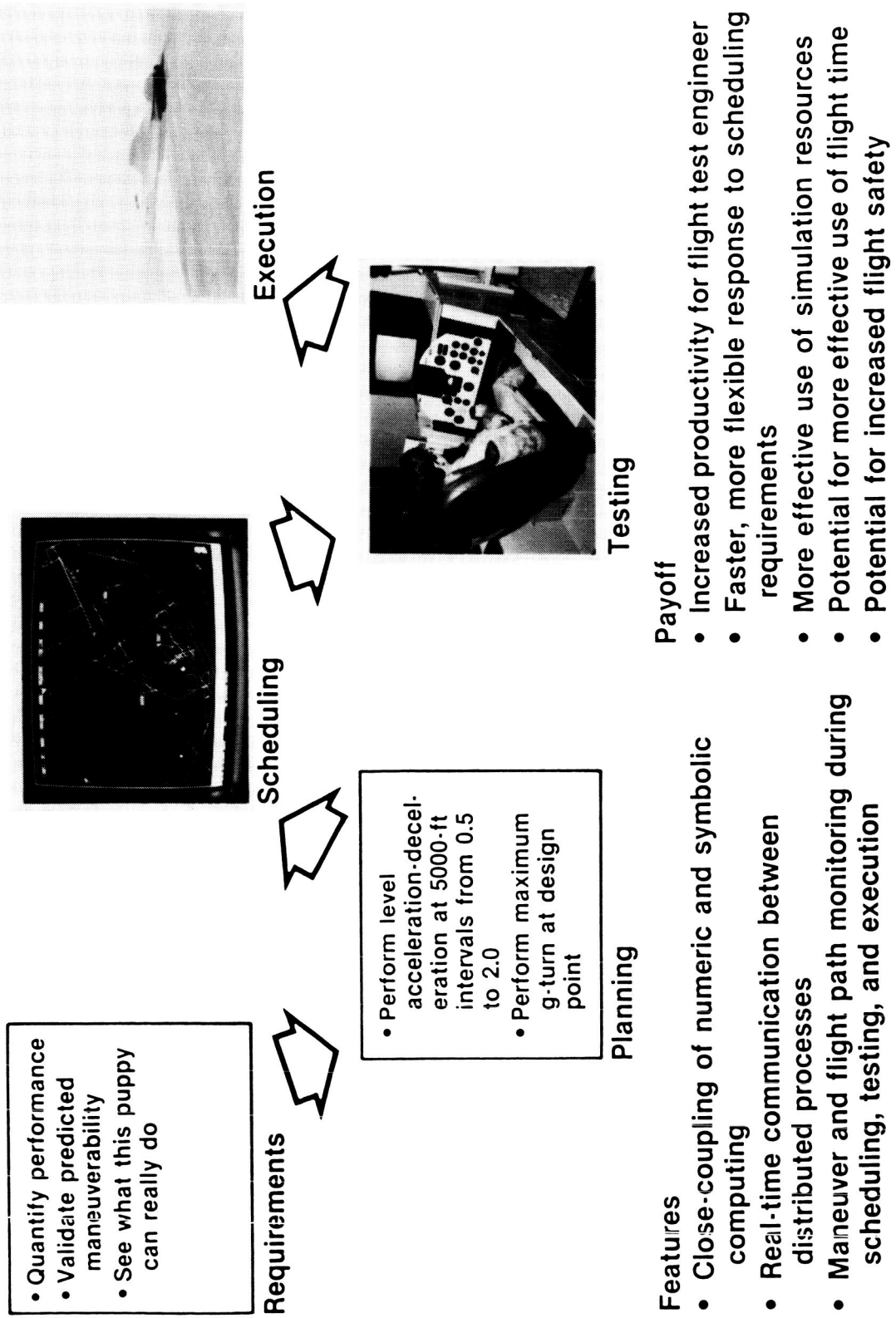
The Automated Flight Test Management System was chosen as the vehicle for developing and demonstrating the initial configuration of the ground-based AI-network portion of the rapid-prototyping facility. The demonstration system utilized a distributed processing network combining symbolic and numeric computers. In one configuration, eight separate processes executed on four separate processors communicated in real-time through various combinations of shared memory and Ethernet connections.

The ATMS provides the capability of automating the process of flight test planning and management by providing the framework of a system to proceed from flight test requirements to flight execution and monitoring with minimal human intervention.

The accomplishments of the Aircraft Automation are: 1) development and demonstration of real-time automated flight test management system (6/88); 2) completion of Phase I development of rapid-prototyping facility (6/88); 3) completion of documentation of batch (10/87) and interactive (7/88) LINEAR program; 4) development of Flight Test Trajectory Controller for HIDEC/F-15 (6/88); 5) preliminary definition (with Langley and Ames-Moffett) of research plan for verification and validation of knowledge-based systems (5/88); 6) new formulation of differential games approach to air combat maneuvering (6/88); and 7) initiation of Phase II SBIR for real-time knowledge-based systems tools (1/88).

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Automated Flight Test Management System (ATMS)



Rapid-Prototyping Facility (Phase 1)

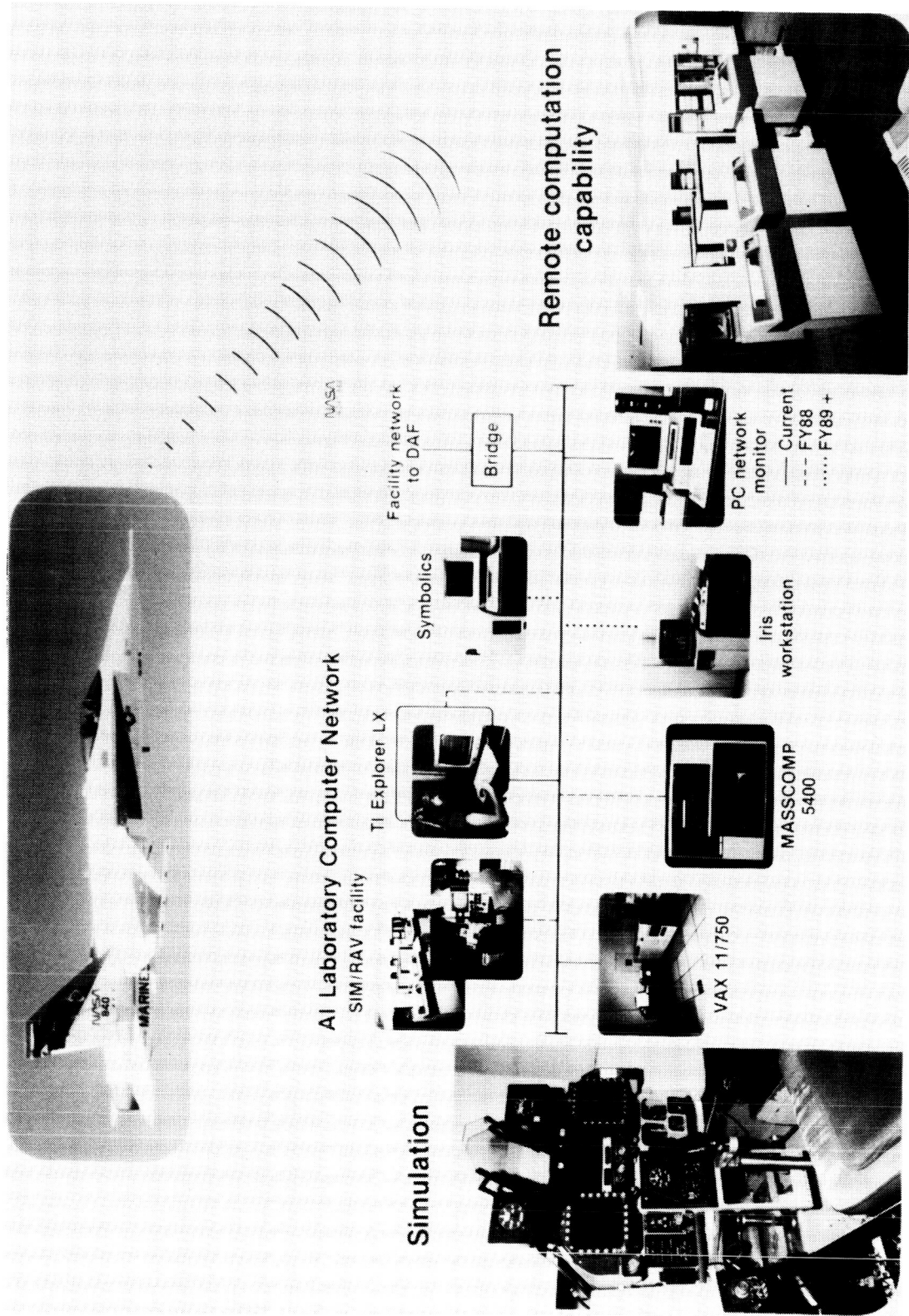
The Phase 1 demonstration of the rapid-prototyping facility extended the remotely augmented vehicle (RAV) concept to include both symbolic and numeric processors capable of supporting flight research with AI-based systems concepts.

A rapid-prototyping facility for flight research in flight systems concepts based on artificial intelligence is essential for the early discovery and solution of many problems associated with the design of new aircraft systems. By resolving these problems early in the design cycle, many more costly and time-consuming exercises can be avoided. Such a rapid-prototyping flight research facility is being developed at the Dryden Flight Research Facility. This flight research facility is an extension of the RAV concept used for testing control law concepts, implementing primary control of remotely piloted research vehicles (RPRVs), and computing cockpit display information. The RAV concept has been used with a variety of aircraft such as the three-eighths scale F-15, the F-8 digital fly-by-wire, and the highly maneuverable aircraft technology vehicles.

This facility will feature a highly instrumented F-18 aircraft capable of being controlled from a ground facility with both conventional minicomputers and symbolic processors. A hardware-in-the-loop simulation supports the facility for development, verification, and validation of system concepts. The objective of this facility is to provide the flexibility necessary to support future flight research programs.

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Rapid-Prototyping Facility for Aircraft Automation Flight Research



Controls and Guidance - Space

The Space Controls and Guidance Research and Technology Program is directed toward enabling the next generation of space transportation systems, large future spacecraft and space systems such as the growth Space Station to have large communication antennas and high precision segmented reflector astrophysical telescopes. The new generation of transportation vehicles has demanding requirements to provide for an order of magnitude reduction in cost as well as an increase in capability. The future orbital facilities have demanding control requirements for pointing and stabilization, momentum management, build-up and growth accommodation, and disturbance management.

To address these advanced requirements, the research and technology program for Space Controls and Guidance is designed to provide the generic technology base to support the implementation of advanced guidance, navigation, and control (GN&C). This technology has the capability to provide for a large reduction in both the number of people who plan and generate the mission software and the people necessary later to provide for mission control. The early incorporation of this technology into the system studies for new vehicles will also positively impact vehicle design concepts to ensure the full realization of potential benefits.

The area of computational controls will be stressed in order to develop cost effective, high speed, high fidelity control system simulation and analysis and synthesis tools. The thrust of this work will be to develop methods and software to enable analysis and real-time hardware-in-the-loop simulation of complex spacecraft for control design certification. This capability has the potential of achieving a 4-order-of-magnitude improvement in the ability to rapidly analyze and simulate control systems for very large complex spacecraft.

To address future orbital facilities requirements, an advanced technology program is underway in system identification, distributed control, integrated controls/structures design methods, and advanced sensors and actuators. Because the behavior of large, lightweight per unit area deployable/assembled spacecraft is greatly influenced by the ground environment (principally gravity), the testing and verification activity is both ground- and space-based.

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Fiber Optic Rotation Sensor (FORS)

The objective of the Fiber Optic Rotation Sensor (FORS) task is to develop a 10-year lifetime, low cost, lightweight, highly reliable, navigational grade optical gyroscope with no moving parts. FORS is based on semiconductor lasers, fiber optic waveguides and integrated optical circuits operating at 1.3 micron wavelength.

The exploded view shows a drawing of a three-axis advanced inertial reference unit incorporating FORS. Full single-axis-redundancy is achieved through the use of four independent single-axis gyros. Three of these gyros are mounted with their sensing axes orthogonal to one another while the fourth is skewed to provide redundancy for any axis.

Each single FORS channel incorporates an advanced integrated optic circuit and will perform all key signal processing functions. FORS will feature a closed-loop, phase-nulling design, which provides for operation over a wide range of rotation rates. Moreover, FORS will be rate-integrating, providing incremental angular position readout in the form of "optical beats." In this sense, FORS resembles a ring laser gyro (RLG), but does not suffer the RLG's tendency to lock-in at low rotation rates.

The advanced eight-component integrated optics circuit, fabricated for JPL by AT&T Bell Labs, consists of waveguides, polarizers, beam splitters and modulators integrated onto a single substrate. The circuit has been assembled in an advanced fiber gyro breadboard and is presently undergoing functional and environmental tests at JPL. The gyro has been operated closed loop and the optical beat readout concept demonstrated. Random walk performance of 4×10^{-3} deg/ $\sqrt{\text{Hr}}$, which is 2 times the theoretical limit of this configuration, was obtained.

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Aeroassist Flight Experiment Guidance "Quiet Time"

The science experiments on the Aeroassist Flight Experiment (AFE) are adversely affected by reaction control system (RCS) jet firings during the portion of the trajectory when nonequilibrium conditions exist (just prior to perigee). An ideal solution from the science point of view would be to cut off the Guidance and Control (G&C) system for 30 sec in the region of maximum science interest. The objectives of this study are: 1) to determine if the G&C system could be cut off for a 30-sec period without losing the ability to recover the vehicle; and 2) to develop techniques for accomplishing this goal.

A baseline guidance system, developed by JSC has been chosen for the AFE. This guidance system has been integrated into the Program to Optimize Simulated Trajectories (POST) as a guidance subroutine. This simulation has been used to examine various techniques to accomplish the "quiet time" objective using different atmospheric models and different models for the transition between relatively low altitude continuum flow and relatively high altitude molecular flow representations for the aerodynamic lift and drag on the vehicle.

A set of gains for the guidance system has been determined that result in trajectories having a final apogee altitude within 5% of the desired, and final inclination angles within 1% of the desired for two different atmospheric models and five different transition models. Using these gains, a 20-sec "quiet time" was found to be achievable with the baseline guidance and a 30-sec "quiet time" is possible. The certainty of attaining a 30-sec "quiet time" is highly dependent on dispersions resulting from system and atmospheric uncertainties.

The overall significance of this work is the ability to enhance the scientific output of the AFE by eliminating the RCS firings during part of the flight when the major science experiments are taking place. The results so far indicate that the ability to achieve 30 sec of "quiet time" is probable but not yet completely determined.

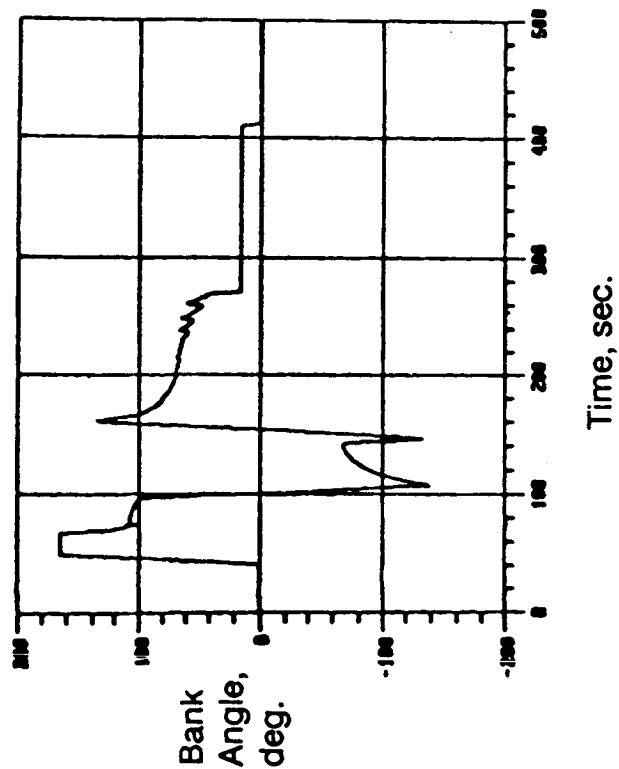
Work will continue on techniques to modify the baseline guidance system to allow 30 sec of "quiet time" and still ensure a safe recovery. This will also be investigated for other guidance systems proposed for the AFE.

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Scott A. Striepe, LaRC (804) 864-4512

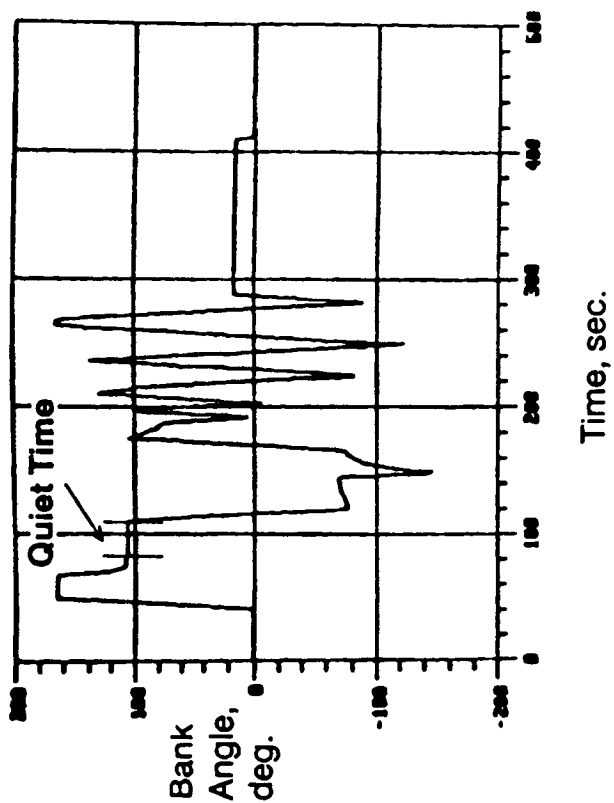
EFFECT OF "QUIET TIME" ON AFE GUIDANCE COMMANDS

CAST

No "Quiet Time"



30-second "Quiet Time"



Advanced Control Evaluation for Structures (ACES) Program

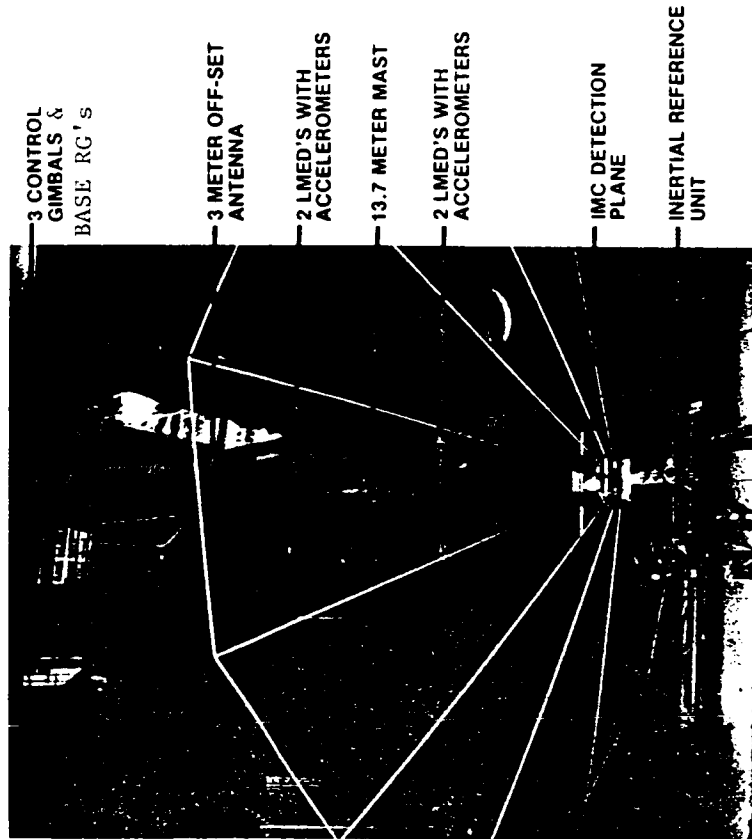
Currently the Single Structure Control (SSC) Laboratory is functional and has been used to demonstrate several control techniques that were developed for LSS. Located at NASA/MSFC in a high bay building, the SSC laboratory contains: 1) a flexible test structure; 2) a Base Excitation Table (BET) for inducing prescribed vibrations and disturbances into the structure; 3) a payload mounting plate attached to a three-axis pointing mount assembly; 4) Linear Momentum Exchange Devices (LMEDs) for damping beam vibrations; 5) assorted sensors (accelerometers, rate gyroscopes) at several structure locations; 6) an Image Motion Compensation (IMC) system for optical pointing; and 7) a computer/telemetry system (ACES configuration). The ACES configuration contains many closely spaced, low frequency modes (43 modes under 8 Hz), which are lightly damped (<2%).

The goals of the SSC Lab are to apply and to implement control design techniques on a realistic LSS and to evaluate performance of LSS controllers. The control design techniques that have been implemented on the ACES configuration are: 1) a decentralized pole placement; 2) Model Error Sensitivity Suppression (MESS); 3) High Authority Control/Low Authority Control (HAC/LAC); and 4) Positivity. Because of the limited optical detector size (4" x 4"), only a time analysis was performed on each control concept.

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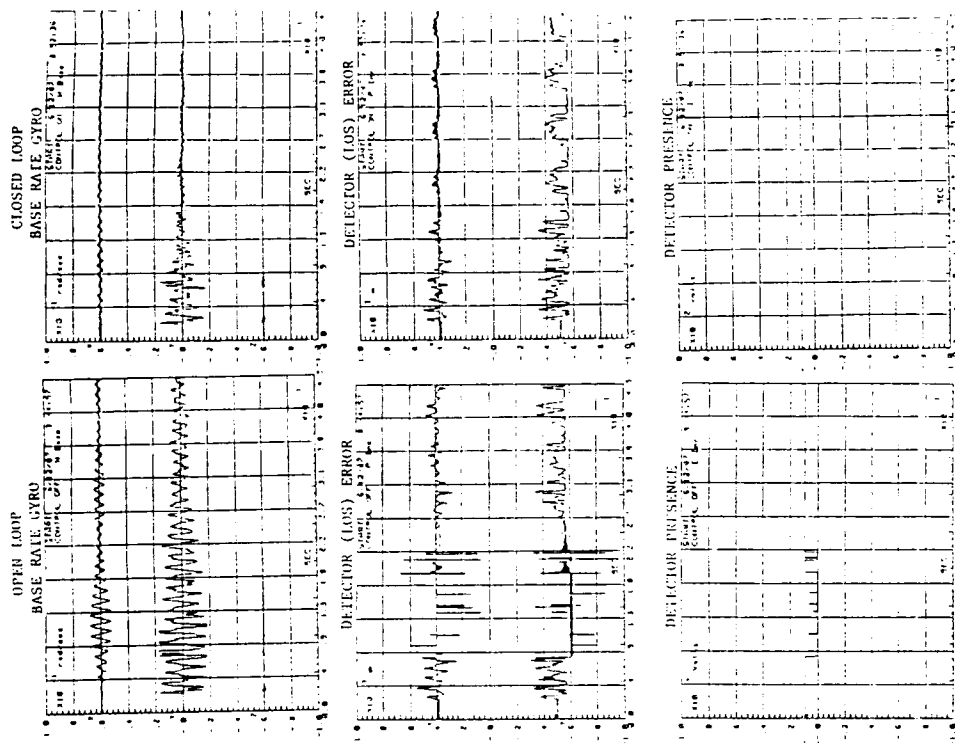
ADVANCED CONTROL EVALUATION FOR STRUCTURES (ACES)-I

OAS-T



LMED: LINEAR MOMENTUM EXCHANGE DEVICES
IMC: IMAGE MOTION COMPENSATION

RESPONSES TO RCS FIRING



Landing Analysis for Mars Sample Return Mission

A key area of the Mars Rover Sample Return Mission (MRSR) is the landing of the rover and the ascent vehicles on the Martian surface. Although the Viking program successfully landed two probes on Mars, subsequent analysis of the size and distribution of rocks in the vicinity of the landers indicated that the probability of failure during landing was greater than originally estimated. For a sample return mission a failure probability greater than 1% is unacceptable. The Viking landers were not steered to a specific target point on the surface. The MRSR landings must be near a site of interesting geology in order to maximize the scientific return. The probability of failure during landing can be reduced and the requirement to land near an interesting site can be achieved by use of precision navigation techniques during the deorbit, entry, and landing in combination with a hazard avoidance technique for the final phase of landing.

During FY88 the Johnson Space Center in collaboration with the JPL conducted a prephase A study to identify requirements and develop preliminary concepts for a MRSR mission. In support of this study the Avionics Systems Division at JSC investigated guidance and navigation techniques that could make a precision landing on Mars possible. Study areas included: 1) optical navigation using sightings of the outer Martian moon Deimos during the Mars approach phase; 2) augmenting the inertial navigation system with landmark tracking and tracking of an orbiter vehicle during entry; 3) guidance and performance analysis for the chute and powered phase of landing; and 4) guidance interface requirements for a hazard avoidance system during the powered phase of landing.

Initial study results indicate that entry interface flight path errors for the aerocapture phase can be reduced to about 0.5 degrees (3 sigma) by using sightings on Deimos. This is significant since it implies that an L/D in the range of 0.5 to 1.0 for the aerocapture vehicle may be acceptable. For a landing from a 500 x 500 km orbit a 4-km footprint can be achieved with a moderately accurate IMU. The footprint can be reduced to about 1.0 km by tracking the orbiter during the descent. Chute performance studies indicate that a ballistic chute is adequate. A powered flight guidance system similar to that used for the LEM landings on the moon was evaluated for the final phase of landing. Maneuverability during the powered phase was shown to be in the range of 1.5 to 3.0 km, which is sufficient to take out knowledge errors that exist at that point. A pinpoint landing on Mars is possible.

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MARS SURFACE RENDEZVOUS

OASIS



Multibody Modeling and Control: CONTOPS

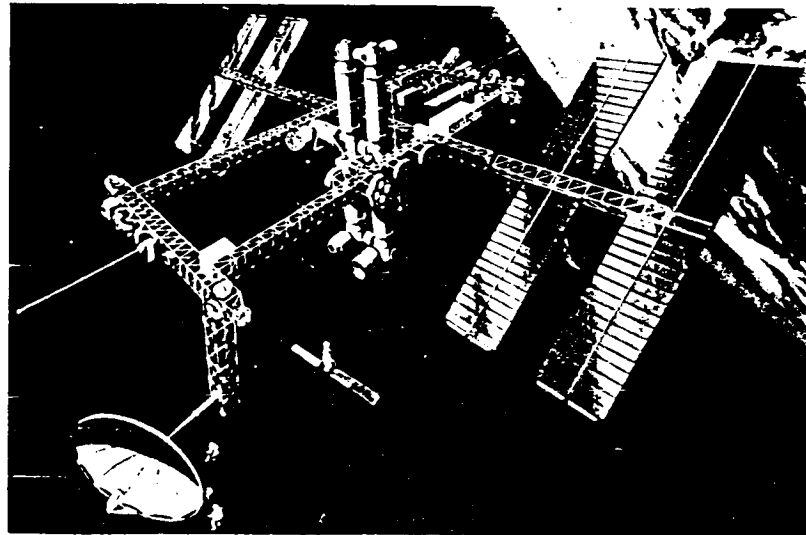
The CONTOPS program is a user-friendly computer analysis tool that can simulate the dynamics and control of a closed-tree topology of flexible bodies. The following features were incorporated into the CONTOPS program during FY88:

- 1) multibody gravity gradient forces and torques,
- 2) multibody aerodynamic forces and torques,
- 3) magnetic field model,
- 4) circular/elliptical geocentric orbit dynamics,
- 5) heliocentric orbit reference frame,
- 6) control moment gyro dynamics,
- 7) reaction wheel dynamics,
- 8) admission of arbitrary boundary conditions,
- 9) inclusion of all second-order model coupling terms, and
- 10) increased selection of dynamic constraints.

Currently CONTOPS is being used in the Spacelab program, the Space Telescope program, and the IUS program with at least 23 users from industry, academe, and government. In addition, a five-year program has been effected for Multibody Modeling and Verification (MMV).

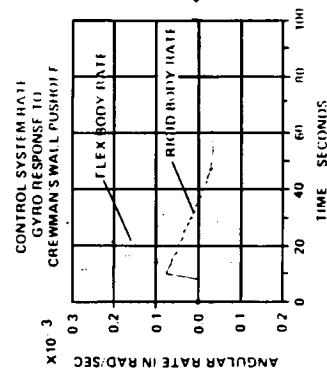
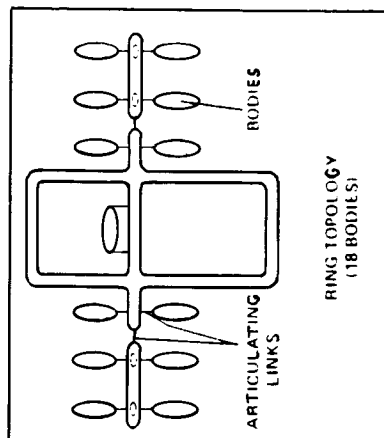
TECHNICAL CONTACT: H.W. Waites, MSFC (205) 544-1441

NON-LINEAR SIMULATION AND MODELING



SIGNIFICANT FEATURES

- MODULAR CONCEPT ALLOWS RAPID RECONFIGURATION
- MODELS LARGE ANGLE ROTATIONS OF APPENDAGES
- CHAIN, TREE AND RING TOPOLOGIES HANDLED
- VARIETY OF CONTROL MODULES AVAILABLE



Single Step Optimal Control Validation on a Computer Model of SCOLE

The objective of this research is to develop and validate control concepts for flexible space structures, which can readily be implemented on real-world hardware. These control algorithms must be capable of utilizing a complement of actuators composed of a mixture of on-off thrusters (non-linear actuators) and saturation limited, proportional reaction wheels (linear actuators) in an efficient manner.

The test configuration for this investigation is a mathematical representation of the Spacecraft Control Laboratory Experiment (SCOLE). Two control algorithms based on Single Step Optimal Control (SSOC), found in the literature, have been adapted to evaluate their effectiveness for vibration suppression. SSOC treats the optimization problem as one of parameter optimization. The given time interval of control interest is divided into subintervals and a cost function for each subinterval is defined. For the SCOLE, the cost function is the total vibrational energy and control effort. This cost function is minimized, without constraints, with respect to the control over each subinterval. The constraints on the individual control inputs are taken into account by replacing the calculated values with the bounded values whenever the bounds are reached.

This research has demonstrated that the minimum control effort laws selected for this investigation can successfully damp vibrations of the SCOLE configuration simulation, with the different types of actuators working in unison as shown on the attached figure. Of the two algorithms evaluated, the one developed by Floyd was found to be relatively simple and computationally efficient and yet yielded a practically identical performance. Because of its relative simplicity, it can be implemented on real-world computers for hardware-in-the-loop evaluations.

This research has demonstrated that minimum control effort laws employing a mixture of on-off and proportional actuators can be implemented. The need for such control approaches is evident since future large space structures will utilize a mix of actuators for maneuvering as well as for fine pointing and articulation.

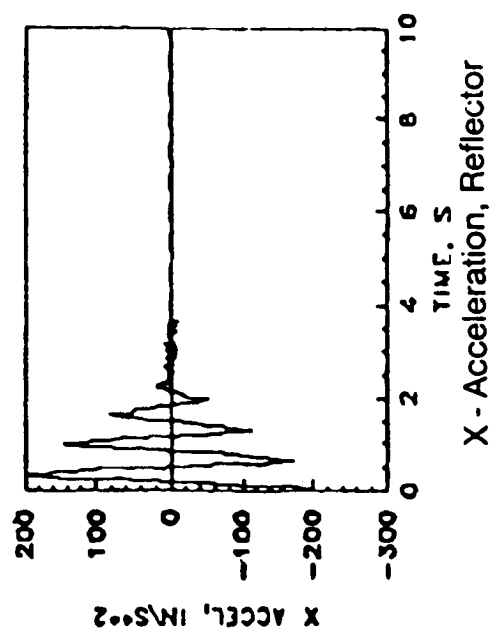
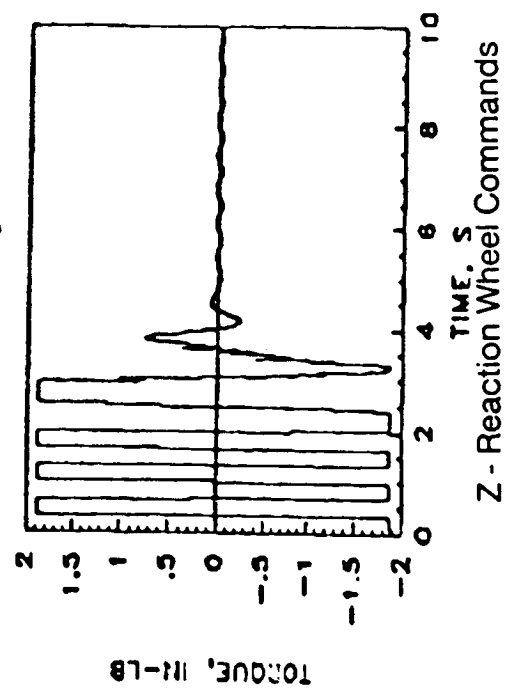
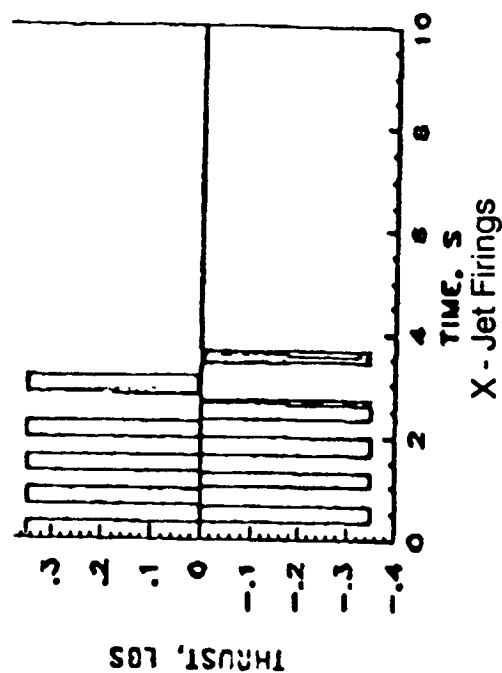
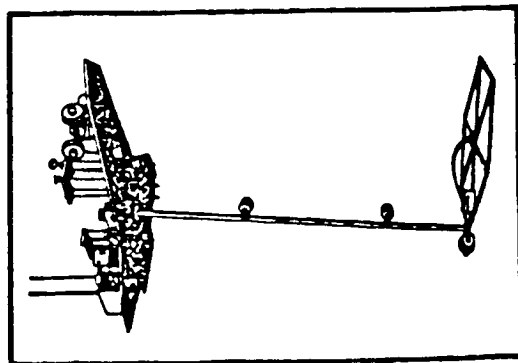
Future work includes the real time evaluation of the SSOC algorithm on the SCOLE apparatus. SSOC will be applied to the freely suspended SCOLE configuration where slewing and pointing problems will be studied. Capability for vibration suppression will also be verified.

TECHNICAL CONTACT:

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SCOLE SIMULATION RESULTS

OAS-T



Robust Model-Based Controller Synthesis for the SCOLE Configuration

The objective of this research is to develop a multivariable frequency domain compensator design approach for flexible spacecraft, which produces controllers meeting performance requirements and possesses robustness to unmodeled high-frequency structural dynamics.

The design approach employed ORACLS and multivariable frequency domain analysis software and applied a modification of the Linear Quadratic Gaussian (LQG)/Loop Transfer Recovery (LTR) method with a frequency domain stability robustness criteria to a finite-dimensional design model. It also employed order-reduction methodology based on Stable Factorization theory to seek a low-order compensator satisfying the stability-performance-robustness design objectives.

The foregoing design approach has been applied to the SCOLE flight configuration. Results indicate that a tenth-order reduced-order compensator (ROC) can be used to meet a representative set of stability-performance-robustness conditions for the 26th-order SCOLE model without destabilizing spillover effects. It was discovered that order reduction can cause a reduction in stability robustness margin as illustrated on the graphic. The graphic depicts the stability robustness criteria. The distance between the upper and lower curves gives a measure of robustness margin. The dip in the upper curve at 5.1 rad/sec (the frequency of the SCOLE third elastic mode.1) was not present prior to order reduction. Results of this study have been presented at the 20th Southeastern Symposium on System Theory, in Charlotte, NC.

Since the SCOLE configuration is representative of many proposed spaceflight experiments, the results and design techniques developed should potentially be applicable to a wide range of large space structure control problems.

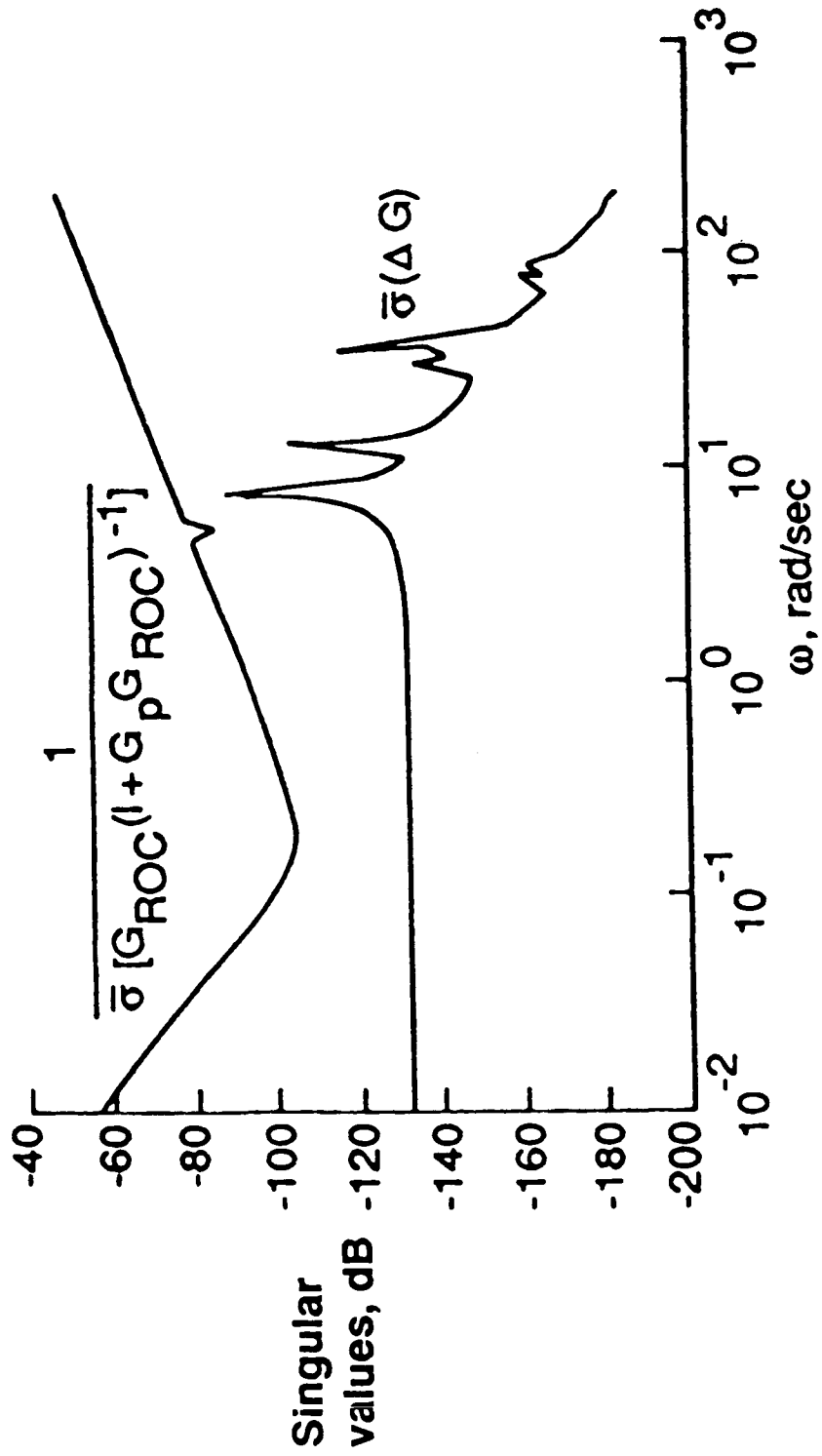
In the future efforts will be continued to refine and further apply the design methodology.

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STABILITY ROBUSTNESS WITH REDUCED ORDER COMPENSATOR

OAS-T



ADA Impact on FCS

The ADA software language is the latest innovation in structured design of software and provides additional capabilities over earlier languages for the design, buildup and maintenance of large software systems such as: multitasking, data abstraction, strong data typing, and commonality. However, these improvements do not come without a price. ADA carries some overhead penalties into runtime operations to provide error checking, etc. It is still unclear whether the state of ADA development is such that it will be able to support a flight program with time critical requirements such as those of large high-speed digital autopilots.

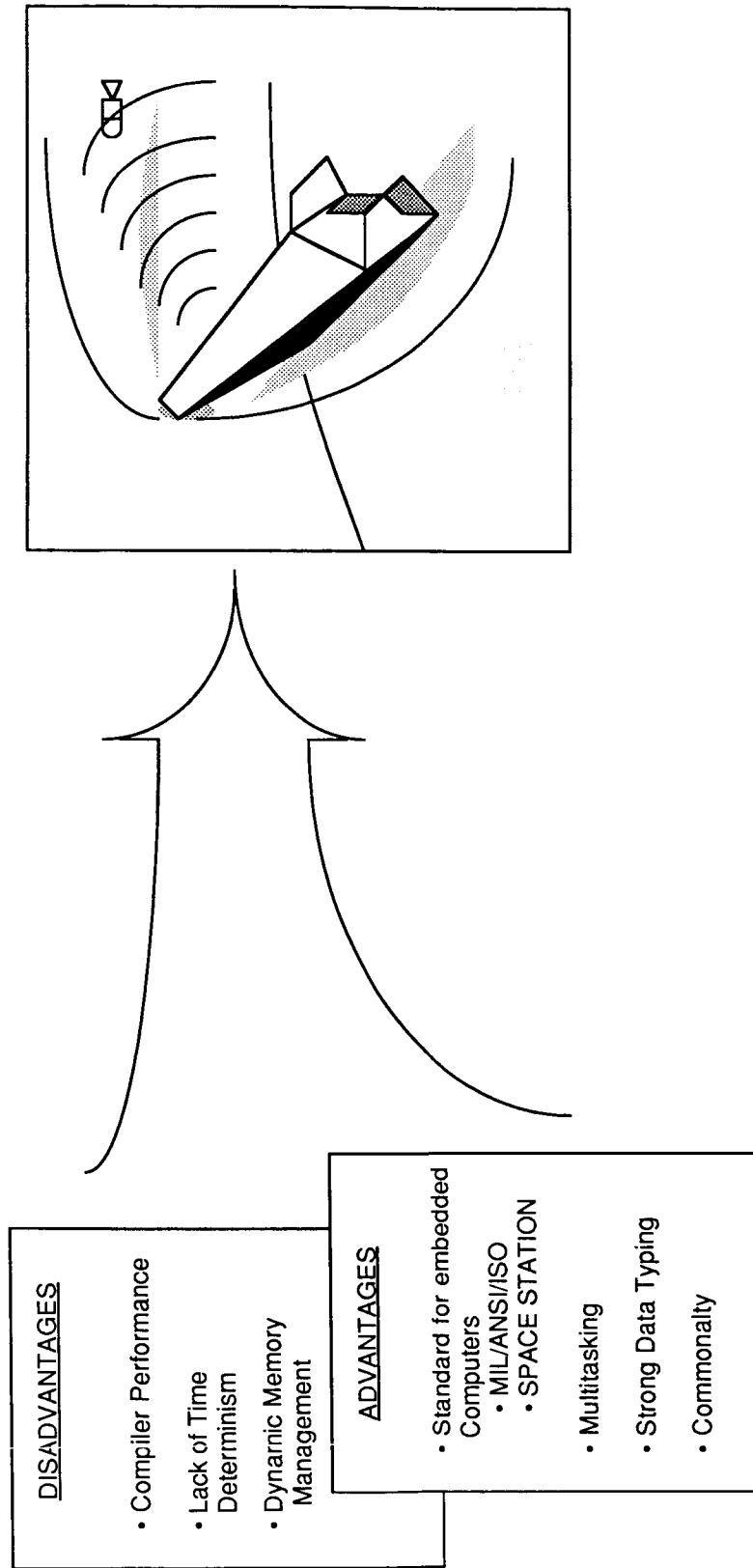
The Johnson Space Center is investigating the impact of the ADA language on a large flight control system (FCS). For this study the version of the Shuttle ascent flight control system used in the single string backup flight system will be coded in ADA. The coding will be done in a manner to take advantage of the unique ADA features. Runtime performance between the existing HAL version and the newly developed ADA version will be compared.

During FY88 several candidate autopilots were reviewed for conversion to ADA. Options included the Orbiter backup flight system (BFS), OEX advanced autopilot (OEX-AAP), and a single axis autopilot developed in-house for test purposes. Although the single axis autopilot would have been easiest to recode it had limited long-term benefits. The BFS and OEX-AAP were flown on the Shuttle and coded in HAL/S. The BFS was selected because it offers long-term capability to include sequencing, displays, guidance, navigation, and system management functions should it be advantageous to recode these functions in ADA also. Program redesign has begun and initial coded packages are expected by the end of CY88. Open loop timing of ADA code will be conducted during FY89. A long-term plan with multiple optional phases will be developed in FY89.

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ADA IMPACT ON FCS

OAS-T



- STUDY TO DETERMINE IMPACT OF ADA ON A LARGE FLIGHT CONTROL SYSTEM (FCS)
- INITIAL PHASE USES SHUTTLE BACKUP FCS
 - RECODE BFS FCS IN ADA
 - DETERMINE OPEN LOOP TIMING OF ADA CODE FOR CRITICAL PATHS
- LONG-TERM PLAN TO COMPARE CLOSED LOOP PERFORMANCE IN REALISTIC ENVIRONMENT

Guidance, Navigation, and Control of Future Aeromaneuvering Vehicles

Many future space missions are enabled or enhanced by the use of aerodynamic forces at hypersonic speeds to modify a space vehicle's trajectory. Mission applications of this type include: 1) aerocapture into a bound orbit about the Earth or another planet; 2) aerobraking to reduce the size and eccentricity of an elliptical orbit; 3) synergetic plane changes using both propulsive and aerodynamic forces; and 4) descent from orbit to a planetary surface. In each case, the efficient use of a planetary atmosphere can substantially reduce propellant requirements and overall mission costs.

The benefits of aerobraking and aeromaneuvering can be achieved only if a space vehicle's trajectory can be controlled to a high degree of accuracy as the vehicle passes through the atmosphere. This is made difficult by the fact that the atmospheric density and vehicle aerodynamic properties are not known sufficiently well in advance, in addition to the fact that entry conditions cannot be controlled precisely. Thus, the onboard guidance, navigation, and control subsystem must be able to determine in real time the true flight environment and quickly adapt to that environment. In many applications the required guidance and navigation computations cannot be performed on the ground due to round-trip light time or communications blackout considerations.

For several years work has been underway at the Jet Propulsion Laboratory designing atmospheric trajectories that minimize propellant consumption while also minimizing such vehicle design drivers as maximum heating rate, total heat input, and maximum acceleration. Also under development are autonomous, onboard, fault-tolerant guidance, navigation, and control algorithms that accurately control atmospheric exit or landing conditions.

During the past year efforts have been focused in two main areas. The work performed in-house has been concentrated on planetary landing applications, as in a Mars Rover Sample Return mission. A navigation filter and a guidance scheme have been developed for descent from orbit to the parachute deployment point above a planetary surface. These guidance and navigation schemes have been integrated into a software simulation and found to produce much more accurate landings than were achieved in the Viking mission.

In addition, work on synergetic plane changes has been performed under contract at the University of Michigan, the University of Texas at Austin, and Rice University. Characteristics of optimal trajectories for multiple-revolution plane changes have been determined. Some simple, near-optimal guidance strategies for large plane changes, which are suitable for onboard implementation, have also been developed.

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GUIDANCE, NAVIGATION AND CONTROL OF FUTURE AEROMANEUVERING VEHICLES

ACCOMPLISHMENTS:

- MARS LANDING APPLICATIONS
- DEVELOPED GUIDANCE SCHEME AND NAVIGATION FILTER
- INTEGRATED ABOVE INTO SOFTWARE SIMULATION AND EVALUATED PERFORMANCE
- SYNERGETIC PLANE CHANGE APPLICATIONS
- DEVELOPED SIMPLE NEAR-OPTIMAL ONBOARD GUIDANCE STRATEGIES FOR LARGE PLANE CHANGES
- DETERMINED OPTIMAL TRAJECTORY CHARACTERISTICS FOR MULTIREVOLUTION PLANE CHANGES

GOALS:

- ACCURATE TRAJECTORY CONTROL IN LANDING AND ORBIT CHANGE APPLICATIONS
- EFFICIENT USE OF PROPELLANT
- RELAXED REQUIREMENTS ON VEHICLE DESIGN/INFLIGHT SATISFACTION OF CONSTRAINTS
- AUTONOMOUS, FAULT-TOLERANT GN&C IMPLEMENTATION

MAPPING/
COMMUNICATIONS
ORBITER

DATA LINK

BICONIC
ENTRY
VEHICLE

ATMOSPHERE
BOUNDARY

LQG Control for the Mini-Mast Experiment

The objective of this effort is to develop a viable test facility for the experimental evaluation of control system concepts for large flexible space structures. To accomplish this goal, a "pathfinder" effort was directed for modeling the facility and validating a pilot control law.

Using a finite element model of the Mini-Mast, the mode shapes and frequencies for the first ten modes were derived. These, in addition to the actuator/sensor complement attendant to this test article, were employed in the definition of the "pathfinder" algorithm. Using the Linear Quadratic Regulator (LQR) method, control gains were then derived. State estimates were derived with Kalman filters from the noisy sensor inputs. Due to reaction mass actuator characteristics, local controllers and force to position command algorithms had to be developed and implemented.

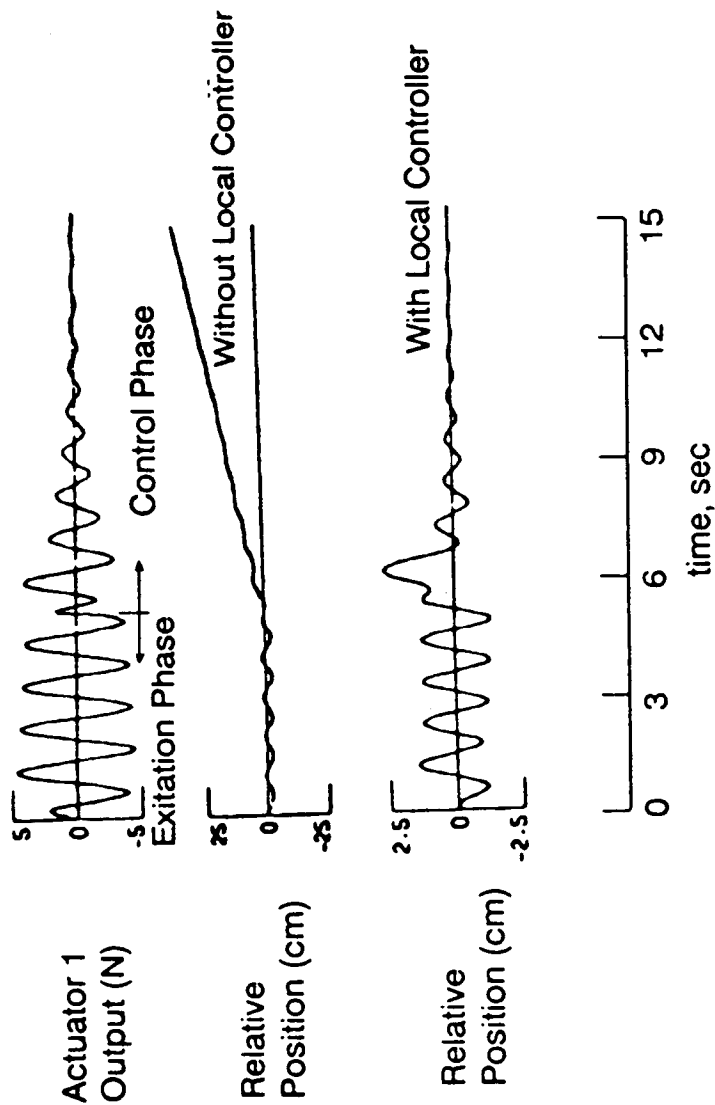
A computer simulation of the test facility was employed to validate this "pathfinder" control concept to verify the process for future candidate guest investigators. The structure was excited by commanding one of the reaction mass actuators. Four of these actuators and one reaction wheel were then used to damp out the vibrations induced in the beam. As is noted in the figure, the induced vibration was readily damped. It is also noted that without proper attention to the physical characteristics of the actuator, control effectiveness can be lost as the actuator drifts to the end of its displacement range. This effect has been overcome through the proper design of local controllers.

This effort has established the viability of the Mini-Mast test article and its attendant sensor/actuator complement as a facility for the evaluation of flexible structures control concepts. It has also demonstrated that this facility will provide a unique resource for the research to be performed by guest investigators in follow-on programs.

In the future simulation results from this task will be compared to experimental results for final validation. In addition, other control techniques will be defined.

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LQG CONTROL SIMULATION FOR THE MINI-MAST EXPERIMENT



Spatial High Accuracy Position Encoding Sensor (SHAPES)

The objective of this task is to develop a control sensor able to make simultaneous three-dimensional position measurements of multiple (up to 50) targets. These measurements need to be made with submillimeter accuracy and with a sufficient data bandwidth for system identification, shape and vibration control of large space structures.

SHAPES, which combines optical angle measurements with time-of-flight range measurements, has the special capability of dynamically tracking many targets simultaneously. The sensor makes use of laser diodes, charge coupled device (CCD) imaging detectors and a picosecond-resolution streak tube to provide 3-D position sensing of retro-reflector targets. Multitarget tracking capability is required to determine both static and dynamic in-orbit characteristics of large antennas, platforms, and the Space Station. SHAPES measurements can be used to check structural alignment and overall geometry during each assembly phase of the Space Station to verify correct assembly. The SHAPES technology can also be used to determine absolute payload pointing/position from navigational base reference position measurements. In addition, a derivative of SHAPES could be used as a rendezvous and docking sensor at ranges up to 40 km. A spin-off of the SHAPES measurement technology task is now being developed by the Space Tracking and Data Systems Office for application to large NASA ground-based antennas.

The FY88 accomplishments include: 1) the completion of the design of the 3-D SHAPES breadboard; and 2) a detailed performance characterization of the SHAPES ranging function. The 3-D breadboard design incorporates a streak tube camera for the ranging function and a commercial CCD camera for angular measurements. The 3-D SHAPES breadboard performance objective is to measure the positions of 24 targets with a resolution of 0.1 mm in range from 1 to 50 m and 0.05 mrad in angular position over a 35 degree FOV at a data update rate of 10 Hz. Two-phase and dual frequency operation of the streak tube will allow unambiguous range measurement to the maximum range of 50 m at the design accuracy. Range measurement accuracy is determined by the accuracy of the range transfer function (RTF) which relates the range to the CCD image position. To provide unambiguous measurement to 50 m the RTF must be known for target motion of $\pm\lambda/16$ (18.75 cm), where λ is the wavelength of the sinusoidal streak tube drive. As part of the performance characterization, the RTF was determined for target motion of ± 18 cm by moving a target in 1-cm intervals, obtaining the CCD image position at each location, and fitting the data to a curve. The results indicate that range measurements, relative to a reference location, can be made with an accuracy of 0.1 mm out to the maximum range of 50 m.

Detailed component designs will be completed, the breadboard fabricated, and 3-D operation verified in FY89.

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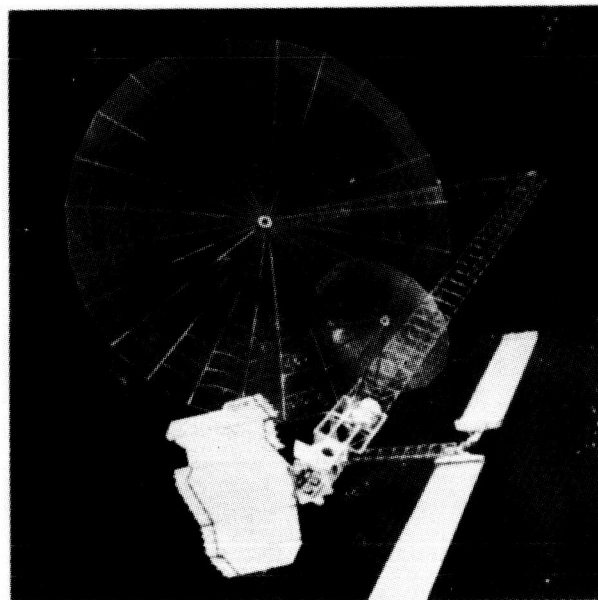
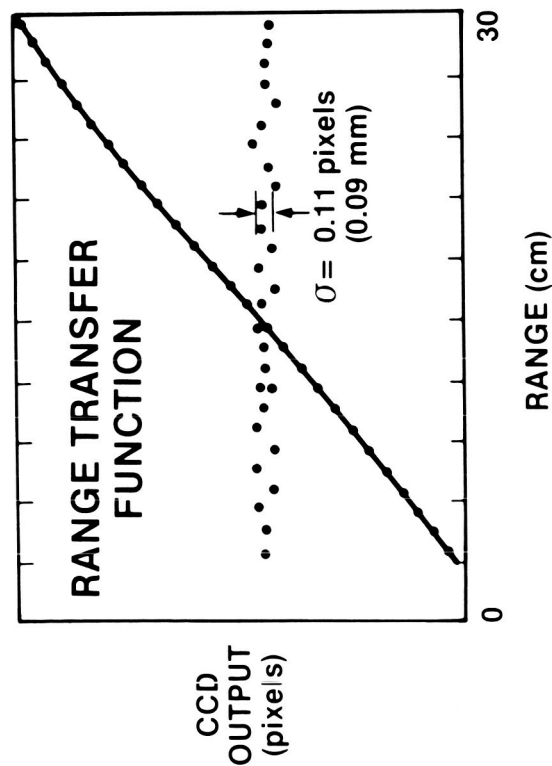
SHAPES: SPATIAL HIGH-ACCURACY POSITION ENCODING SENSOR

PAYOFF

- SENSING FOR STATIC SHAPE AND DYNAMIC CONTROL OF LARGE STRUCTURES
- PAYLOAD POINTING

ACCOMPLISHMENTS

- CHARACTERIZED RANGE FUNCTION
- COMPLETED 3-D BREADBOARD DESIGN FOR TECHNOLOGY DEMONSTRATION
 - 24 TARGETS @ 10 Hz
 - 0.10 mm POSITION ACCURACY
 - 35° FIELD-OF-VIEW
 - 1-50 meter RANGE



Inflight Evaluation of the Structural Integrity of Spacecraft

Future spacecraft such as the Space Station will be larger and more flexible than their predecessors. In many cases, these spacecraft will be assembled on-orbit, and they will be designed to perform missions that will extend over several years. To ensure that these spacecraft can successfully meet their performance goals, it will be necessary to periodically determine whether critical portions of the structure have been fatigued or flawed. In the event that a structural problem is detected, the GN&C system of the spacecraft could be reconfigured to limit operations that might jeopardize the spacecraft's ability to complete its mission. The capability to detect flaws on-orbit is especially important for a manned spacecraft such as the Space Station.

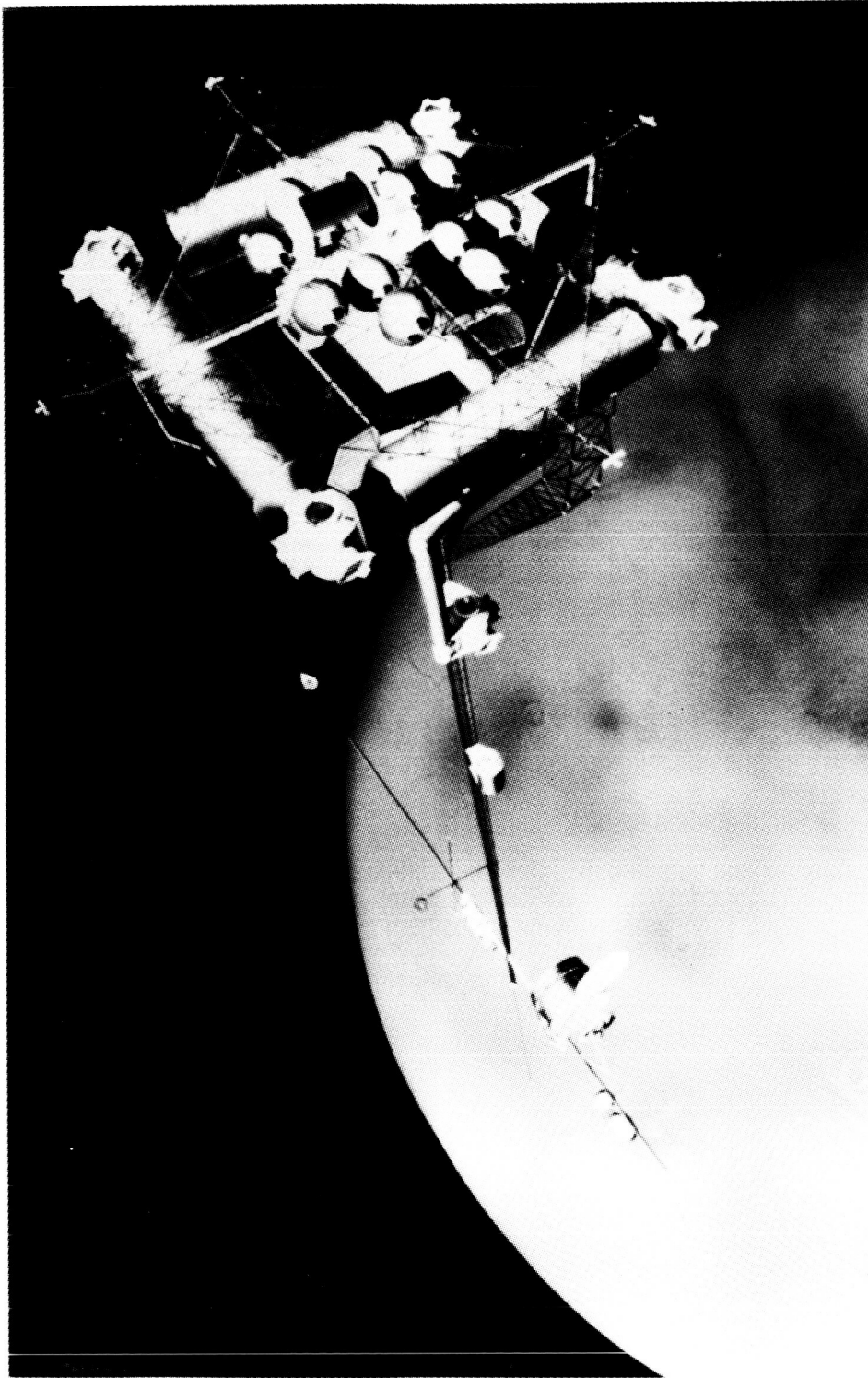
The Johnson Space Center (JSC) has a research program in progress to develop and demonstrate a procedure for evaluating the structural integrity of a spacecraft on-orbit. This procedure uses the pattern of discrepancies in the analytical (modeled) and experimental (measured) values for the frequencies of a spacecraft to determine which structural elements have fatigued or failed. The analytical frequencies will be obtained from the finite element models and the experimental frequencies will be identified from on-orbit data.

The results and accomplishments of this research include the development and demonstration with a simple beam model of a procedure for evaluating the structural integrity of a spacecraft. A laboratory experiment to test the procedure using a free-free beam model has been designed. The experiment will be implemented at the Modal Analysis and Control Laboratory, University of Lowell, MA.

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IN-FLIGHT EVALUATION OF STRUCTURAL INTEGRITY

OASD



Unified Control Structure Modeling and Design

The Unified Control Structure Modeling and Design task has addressed several key issues that arise from pointing accuracy and stability requirements for future flexible spacecraft such as the LDR or VLBI missions. These requirements cannot be met by current control technology state of the art because of the uncertain characterization of system mode shapes, frequencies, and damping ratios. These challenges form the main drivers of control system technology development.

Particular technologies that have been developed keyed to these requirements include a performance-driven modeling methodology wherein model resolution is adjusted with the control design process, model reduction techniques tailored to spacecraft system applications, methodologies for robust control design and tuning that make use of uncertainty knowledge, and a preliminary version of a factorization based synthesis technique that improves numerical speed and accuracy for a generation of control laws. The composite of these technologies lead to a more efficient and accurate design process for flexible structures in which less conservative performance/robustness tradeoffs can be made.

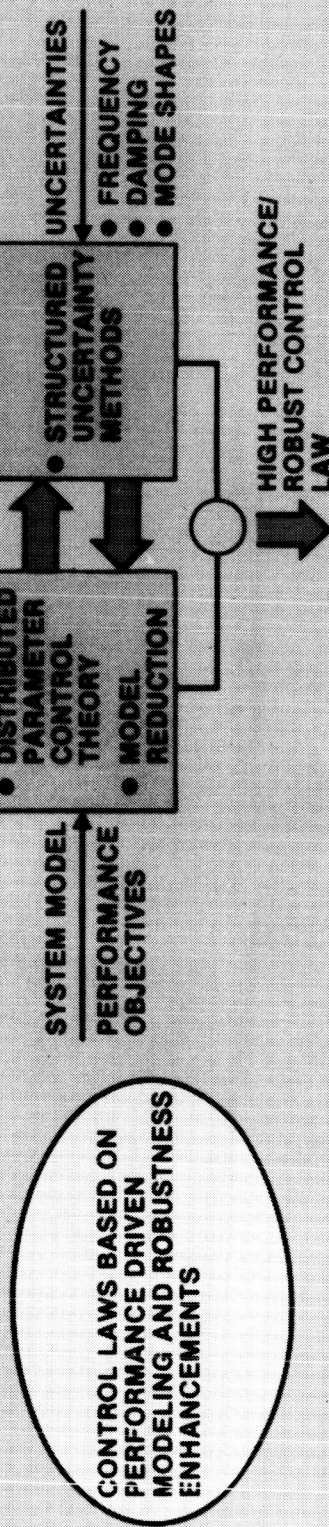
The methods and results of the task have been fully documented. With the participation of university researchers from UCLA approximately two dozen journal and conference articles have been produced over the past three years. The UCLA collaboration has been very fruitful with three Ph.D dissertations written by students supported by the task. In addition to the contributions to the technical literature, a proof of concept experiment of the design process has been successfully demonstrated on the JPL/AFAL antenna test article in which analytical performance-driven modeling and robustness-enhancement methods were combined to yield significant performance improvements over conventional methods.

These component technologies have matured to the point where they represent prime candidates for advanced development as a computational controls tool. Future work will evaluate the technology readiness of the components for this kind of development.

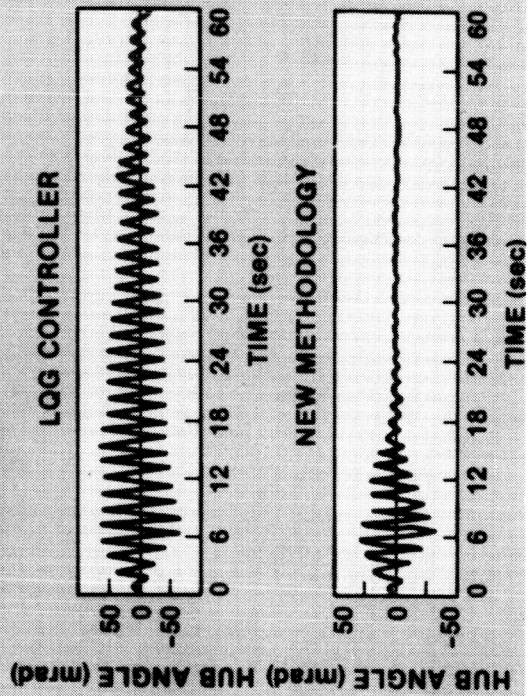
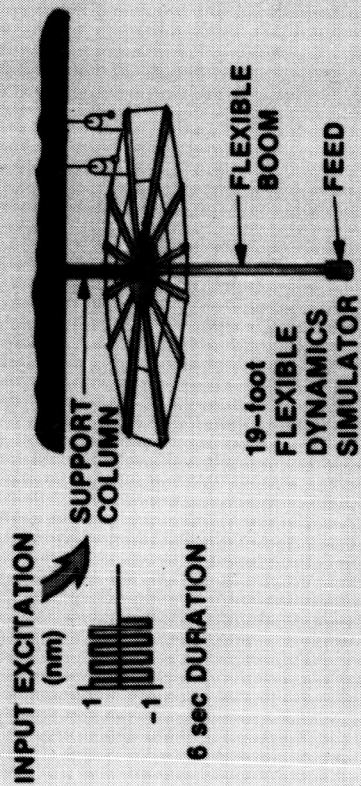
TECHNICAL CONTACTS: Mark Milman, JPL (818) 354-7548
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UNIFIED CONTROL STRUCTURE MODELING AND DESIGN

INTEGRATED DESIGN METHOD



EXPERIMENTAL RESULTS



Computational Controls

Development of complex spacecraft required for the future missions will demand control system analysis and test capabilities that are currently unavailable. In order to design and test such control systems, designers will need to model very high-order linear and nonlinear dynamic systems involving 500-2000 system states. They will need to compute robust, optimal control systems for these models, conduct performance verification simulation, and support system identification and anomaly investigation during mission operations.

The objective of this program is to develop cost effective, high-speed, high fidelity control system simulation, analysis and synthesis methods, and software to achieve a 4-order-of-magnitude improvement over current capabilities to enable space missions in the mid-1990s and beyond.

These challenges can be met by developing advanced numerical techniques and algorithms, including spatially recursive algorithms, automatic component representation preprocessor, parallel computing algorithms, and AI symbolic manipulation preprocessor. The need for rapid response can be fulfilled by developing visualization methods for time-dependent data display, for system synthesis and model verification, and numerical methods for real-time hardware-in-the-loop simulation and system identification.

The principal accomplishment of FY88 has been the completion of an assessment of technology needs, the development of a technical program plan, and the definition of a detailed program for FY88. Technology assessment, steered by the Multibody Simulation Technology (MUST) working group, was carried out by using code and user surveys, a workshop, and working group meetings. The preliminary technology program plan has been reviewed by the Computational Controls planning committee and the MUST working group. The FY89 program is designed to address the highest payoff technology areas such as spatially recursive algorithms, component representation preprocessor, and algorithms for parallel computer architectures. Other activities may include the development of a set of technology requirements, and benchmark problems, and the completion of a verification library.

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COMPUTATIONAL CONTROLS

CHALLENGE:

- TO ACHIEVE A 4 ORDERS-OF-MAGNITUDE IMPROVEMENT IN SPACECRAFT CONTROL DESIGN, MODELING AND SIMULATION TOOLS

RELATIONSHIP TO NASA'S MISSIONS:

- FUNDAMENTAL TOOLS NEEDED FOR FUTURE NASA MISSIONS (EOS, MRSR, LDR,...)
- ENABLING FOR LDR AND LARGE INTERFEROMETER CLASS MISSIONS

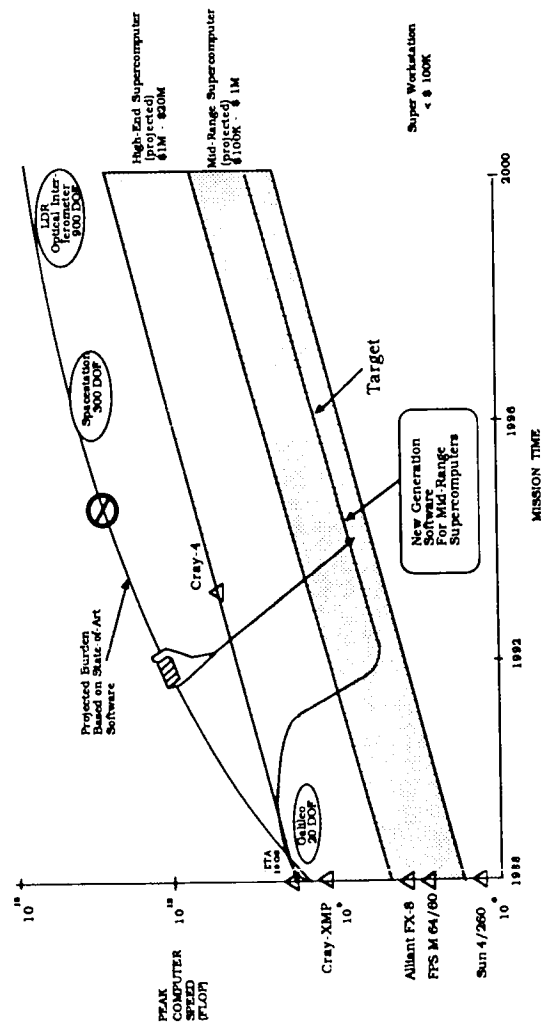
COMPUTATIONAL REQUIREMENTS:

- ENABLE REAL-TIME HARDWARE-IN-THE-LOOP SIMULATION OF COMPLEX (500-2000 DEGREE OF FREEDOM) SPACECRAFT FOR CONTROL DESIGN CERTIFICATION
- IMPROVE CONTROL SYSTEM EVALUATION TURN AROUND TIME BY A FACTOR OF 10 (10 MONTHS - 1 MONTH)
- NEW ALGORITHM FORMULATIONS, INCLUDING SPATIALLY RECURSIVE ALGORITHMS AND AI SYMBOLIC MANIPULATION PREPROCESSOR. NEW ALGORITHMS TO ADAPT RELEVANT EQUATIONS TO PARALLEL ARCHITECTURES AND AUTOMATIC COMPONENT REPRESENTATION TECHNIQUES

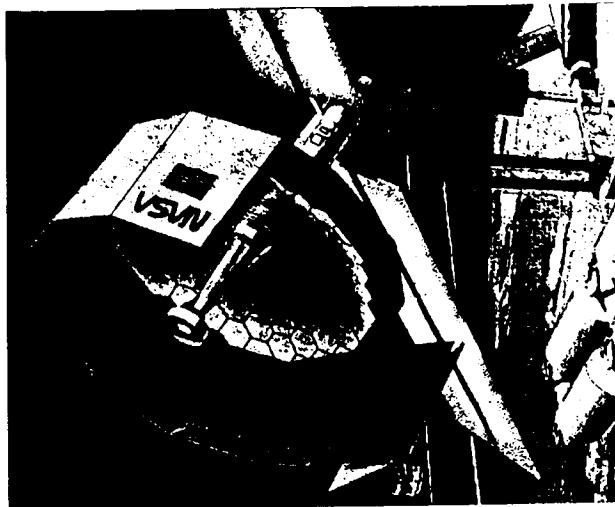
PAYOFF:

- AVOIDANCE OF OCCURRENCES OF CATASTROPHIC MISSION FAILURES
- PRODUCTIVITY INCREASE IN THE DESIGN AND OPERATION OF THE SPACECRAFT

COMPUTATIONAL REQUIREMENTS FOR REAL-TIME HARDWARE-IN-THE-LOOP CONTROL SYSTEM TESTING



EXISTING TOOLS LIMIT TODAY'S CONTROL DESIGN AND VERIFICATION AND ARE INADEQUATE FOR FUTURE NEEDS.



Data Systems

The Data Systems Program consists of research and technology devoted to controlling, processing, storing, manipulating, and analyzing space-derived data. The objectives of the program are to provide the technology advancements needed to enable affordable utilization of space-derived data, to increase substantially the capability for future missions of onboard processing and recording and to provide high speed and high volume computational systems anticipated for missions such as the evolutionary Space Station and Earth Observing System.

The Data Systems Program supports fundamental research in such areas as laser diodes, supports work to select and provide the appropriate onboard processor technology for future NASA missions, and also supports the development of two flight processors with special architectures. The ongoing support for solid state laser research leads directly to the development of a nine laser diode array that is used in the Optical Disk Recorder. The laser research is also focusing some effort applicable to Space Station data handling applications. These devices are being developed to handle both the 300 Mbit/sec basic data rate and the much higher rates needed to support networking and computer internal communications. Complementary research is being supported to characterize the fundamental performance and properties of various alternative networking.

NASA missions require processors that will work very reliably in the space environment. Computer systems for missions in polar orbit and some planetary missions must operate reliably in high radiation environments. The Data Systems Program capitalizes on the dramatic advances in electronics, computer systems, and software that are occurring in both the public and private sectors. It fosters and leads the development of technologies required to meet NASA's unique data systems needs. NASA technical expertise is being applied in cooperative arrangements with DOD, and products from the DOD VHSIC program, and other DOD developments, are being assembled into processors for test and evaluation.

The Advanced Digital SAR Processor includes a special architecture and algorithms to process SAR data. The unit will have a compute rate of 6000 megaflops per second. The Massively Parallel Processor (MPP) is being used for ground processing of space image data, SAR data, and spectral analysis. The MPP utilizes 16,384 processors. The research applications developed on the MPP have verified the expected tremendous computational power of the MPP for the target applications. Researchers outside of NASA in several universities, research centers, and industry have been provided access to the MPP to gain an understanding of the capabilities of the MPP and have applied these unique resources to a broad range of computational problems.

Future objectives through the Civil Space Technology Initiative in High Rate/High Capacity Data include data system architectural studies for new space initiatives, significant advances in technologies and capabilities for onboard image processing, data compression, high volume block access storage, data networks, spectrometry and adaptive sensor control.

PROGRAM MANAGER: Dr. Paul H. Smith
NASA/OAST/RC
Washington, DC 20546

Spaceflight Optical Disk Recorder

High-rate high-capacity data storage has been identified as an enabling capability for future spaceflight missions. To this end, a program has been established to develop a high performance, erasable optical disk recorder with the following features: erasable, rewritable optical media; random access data playback; capacity to one terabit (120 gigabyte); up to 1.8 gigabit per second input and output rate; and configurable, expandable architecture to satisfy various applications.

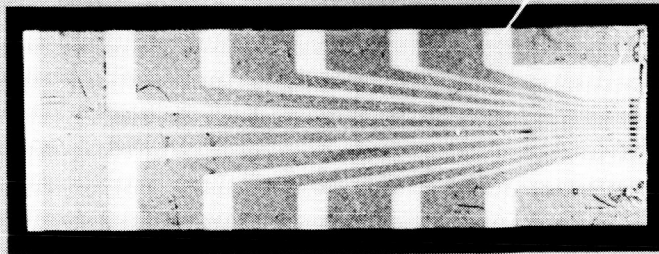
The key technologies that form the basis for the system are 14-inch magneto-optic media, 10-element diode laser arrays, a multi-track electro-optic head, and a versatile system controller. High capacity is due to the areal density of optical media, which is projected to be eight to twenty times that of magnetic media. High rate is obtained by the use of a diode array and supporting electro-optic head to write, read, and erase eight simultaneous data tracks on each media surface. The per head data rate goal is 150 megabits per second. The current concept is to package a dual-sided disk, two heads, and supporting electronics into a disk drive module. An associated modular controller is to be developed to produce a configurable expandable system. Multiple drive modules can be utilized to obtain data rates in excess of one gigabit per second. This rate exceeds that of any other known or planned optical recording device or flight tape recorder.

A phased development is underway involving three separate contractors and a Langley Research Center in-house effort. Other government organizations are participating as well. The current emphasis is on demonstrating the basic technologies followed by a laboratory brassboard demonstration to address fundamental engineering issues.

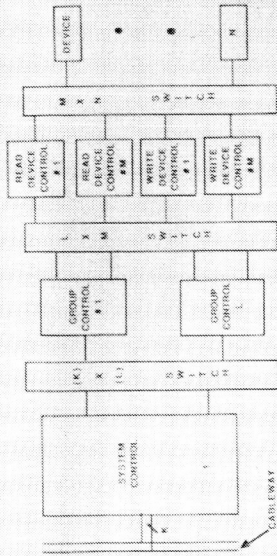
This past year this program produced the world's first individually addressable 10-element linear diode array, and the world's first preformatted, over-coated 14-inch magneto-optic disk. The disk is single-side using aluminum substrate. Two diode arrays have completed 100-hour burn-in tests. The array and disk have been incorporated into a developmental electro-optic head and partial demonstration has been conducted. An overall system architecture has been generated and a preliminary system description document is being prepared for release in August.

TECHNICAL CONTRACT: Dr. T. A. Shull, LaRC, (804) 864-1874

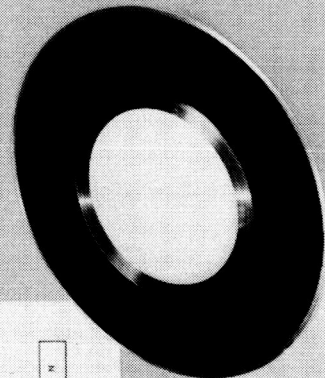
OPTICAL DISK RECORDER



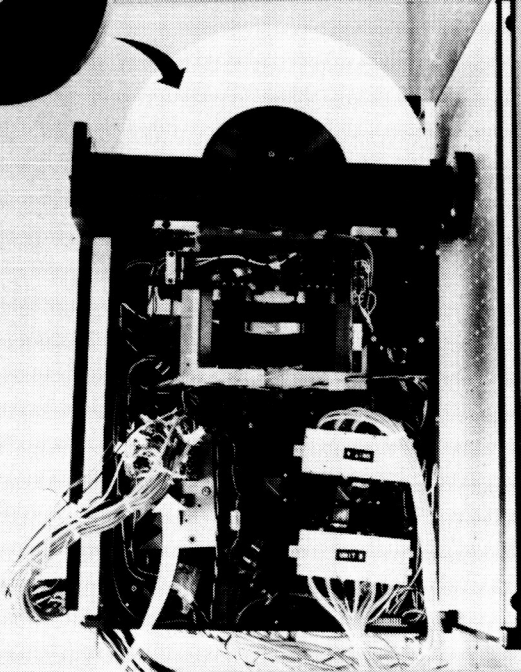
TEN ELEMENT
AlGaAs DIODE
LASER ARRAY
DELIVERED



CONFIGURABLE, EXPANDABLE
SYSTEM ARCHITECTURE



OVERCOATED
PREFORMATTED
MAGNETO-OPTIC
ON AL DISK
DELIVERED



TECHNOLOGY DEMONSTRATION OF ELECTRO-OPTIC HEAD
WRITE/READ/ERASE AT 133 MBPS
8 DATA TRACKS, 1 PILOT TRACK

ERASABLE PROM BASED ON HOPFIELD'S NEURAL NETWORK MODEL
Electronic Neural Networks With Modifiable Synapses

The overall objective of this program is two-fold: 1) To develop a programmable, erasable, read-only electronic associative memory system based on neural network models, and; 2) To demonstrate the use of this adaptive neural network hardware as a "smart" fault-tolerant memory system in highly parallel associative recall and pattern recognition applications. Artificial neural network models, based on the architecture of the human brain promise an extremely robust, fault-tolerant approach to information processing. Electronic implementation of such a network architecture has already been demonstrated at JPL. Such a memory system would be greatly enhanced if the irreversible, non-volatile, microswitches could be replaced with reversible memory elements. Such reprogrammable, smart memory systems with their unique learning abilities, will have a significant impact on a variety of space and defense applications in high-speed target recognition, optimization, and autonomous control operations.

The technical approach involves the development of dense, non-volatile arrays of modifiable connection elements (synapses) based on reversible, thin film microswitch structures; optimization of the system architecture for parallel interfacing of the synaptic arrays with the neuronal decision-making elements; and interfacing the neuronal elements with the synaptic blocks in the selected configuration leading to a demonstration of a "smart" memory system.

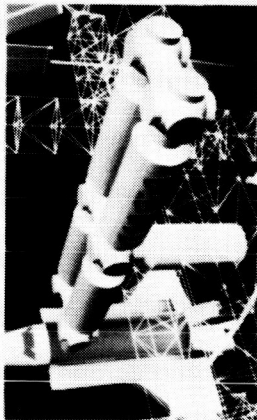
This review period has been highlighted by the first ever demonstration of a non-volatile reversible, fully analog resistive synapse. This tungsten oxide (WO_3) based electrochromic memory device, one of four candidate device structures selected in the initial phase of the program, has far exceeded the objectives set forth. The three terminal test structures exhibit over a 4-order of magnitude of tailorable resistive dynamic range, long-term memory retentivity, and continuous gray scale. Other leading synaptic test devices under investigation include thin film-based floating gate transistors and crystalline silicon-based devices. Furthermore, a powerful software tool, a neural network simulator, has been developed that provides a research environment for investigating neural net applications and optimization of smart memory architectures. The simulator is currently being used to optimize backpropagation learning algorithms, and to evaluate hardware-imposed constraints in its layered, feed-forward, neural net implementation. Such a neural net hardware will capture and store complex and hidden correlations in the incoming information (experience) - and will provide "smart" responses at a high speed even in "fuzzy" situations.

In FY89, the reversible, non-volatile WO_3 and thin film-field effect transistor synaptic devices will be optimized for their programming speed, cyclability, and dynamic range. This will lead to the design for the upward integration of the selected synaptic device into an array structure. In parallel, the ongoing neurocircuit computer simulations will focus on development of problem-specific neural net architectures resulting in hardware designs specifically optimized for space-borne "smart" knowledge bases capable of being updated.

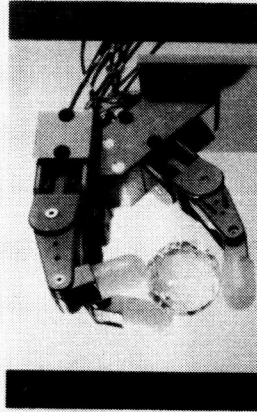
TECHNICAL CONTACT: Anilkumar P. Thakoor, JPL, (818) 354-5557
Don Erickson, JPL, (818) 354-1656

JPL

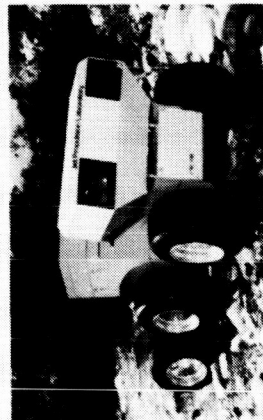
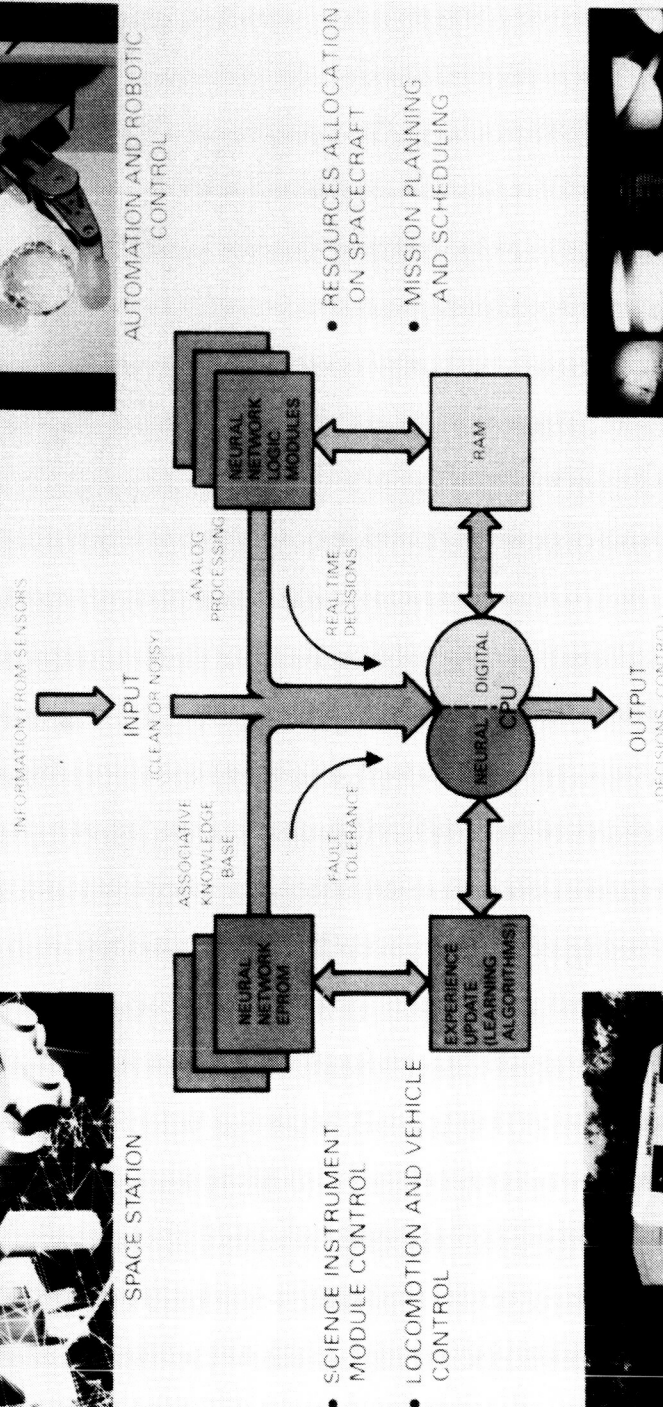
ELECTRONIC NEURAL NETWORKS KNOWLEDGE BASES AND LOGIC MODULES



SPACE STATION



AUTOMATION AND ROBOTIC
CONTROL



AUTONOMOUS ROVER AND
LANDER



TERRESTRIAL APPLICATIONS

RC89-224(3)

Configurable High Rate Processor System (CHRPS)

The Configurable High Rate Processor System (CHRPS) will provide the architecture, system control, and high rate data handling interfaces needed to support onboard compression, information extraction, and automated operations of high rate imaging missions.

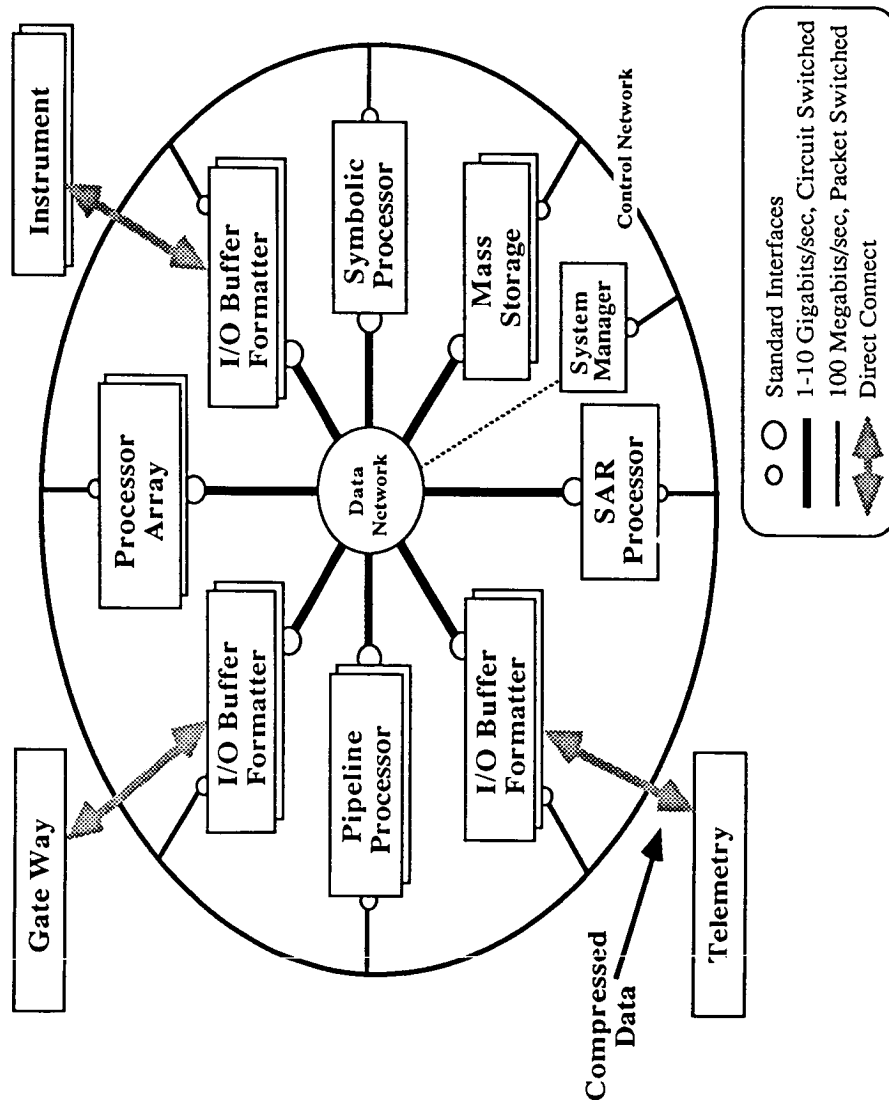
The next generation of imaging sensors will provide measurement capability at finer spectral and spatial resolution, resulting in data rates exceeding the capability of the Tracking and Data Relay Satellite System and exceeding the capacity of ground processing systems and analysis teams. Interdisciplinary studies will require coordinated observations and integrated analysis of data from these sensors. The CSTI Data Systems Program is developing image processing and optical disk recorder technology to support onboard data compression, information extraction, and data buffering for these high rate missions. The CHRPS will apply high rate network technology and develop the packet telemetry handling interfaces to enable the processing and buffering components to be configured for a range of operations from single instrument data compression to multi-sensor fusion and feature extraction. The CHRPS development will produce a phased test bed to demonstrate technology components for project applications such as Eos to support the integration of technology into space platform architectures and to support the evaluation of onboard processing functions.

During FY88, the CHRPS architecture concept was developed, and coordinated efforts with the Eos Project for the Data/Information System Phase B study were initiated. An assessment of candidate DoD and industry technology elements for use in the CHRPS architecture was initiated. A Data Compression Workshop was cosponsored with JPL in May 1988 to bring together instrument and information scientists to begin to map the potential applications and algorithms.

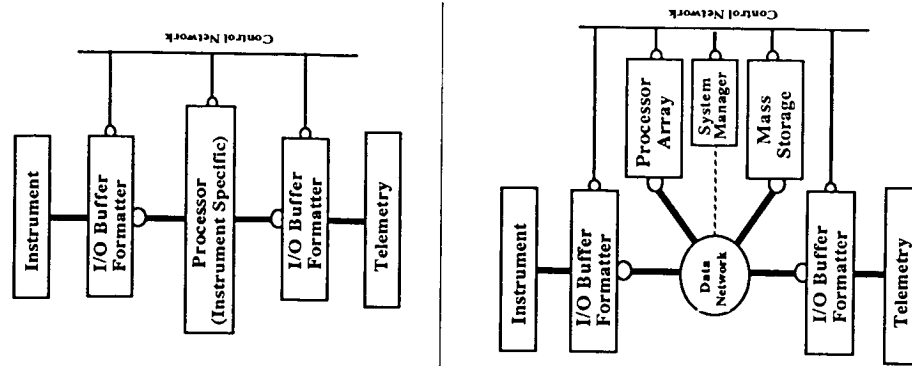
TECHNICAL CONTACT: Dan Dalton, GSFC, (301) 286-5659

CONFIGURABLE HIGH RATE PROCESSOR (CHRP)

CHRP System Concept



Candidate IOC Configurations



RIACS Sparse Distributed Memory (SDM)

One of NASA's grand challenges is machines and systems that are capable of learning to function in places and tasks too remote, hostile or tedious for humans. The Sparse Distributed Memory (SDM) project is investigating the theory and applications of a massively parallel computing architecture that will support the storage and retrieval of sensor and motor patterns characteristic of autonomous systems. The immediate objectives of the project are centered in studies of the memory itself and in the use of the memory to solve problems in speech, vision and robotics. Investigation of methods, including artificial neural systems, for encoding sensory data is an important part of the research. The project began with one scientist in 1986 and has grown to five scientists in 1988, with cooperating work in universities, industry, and government.

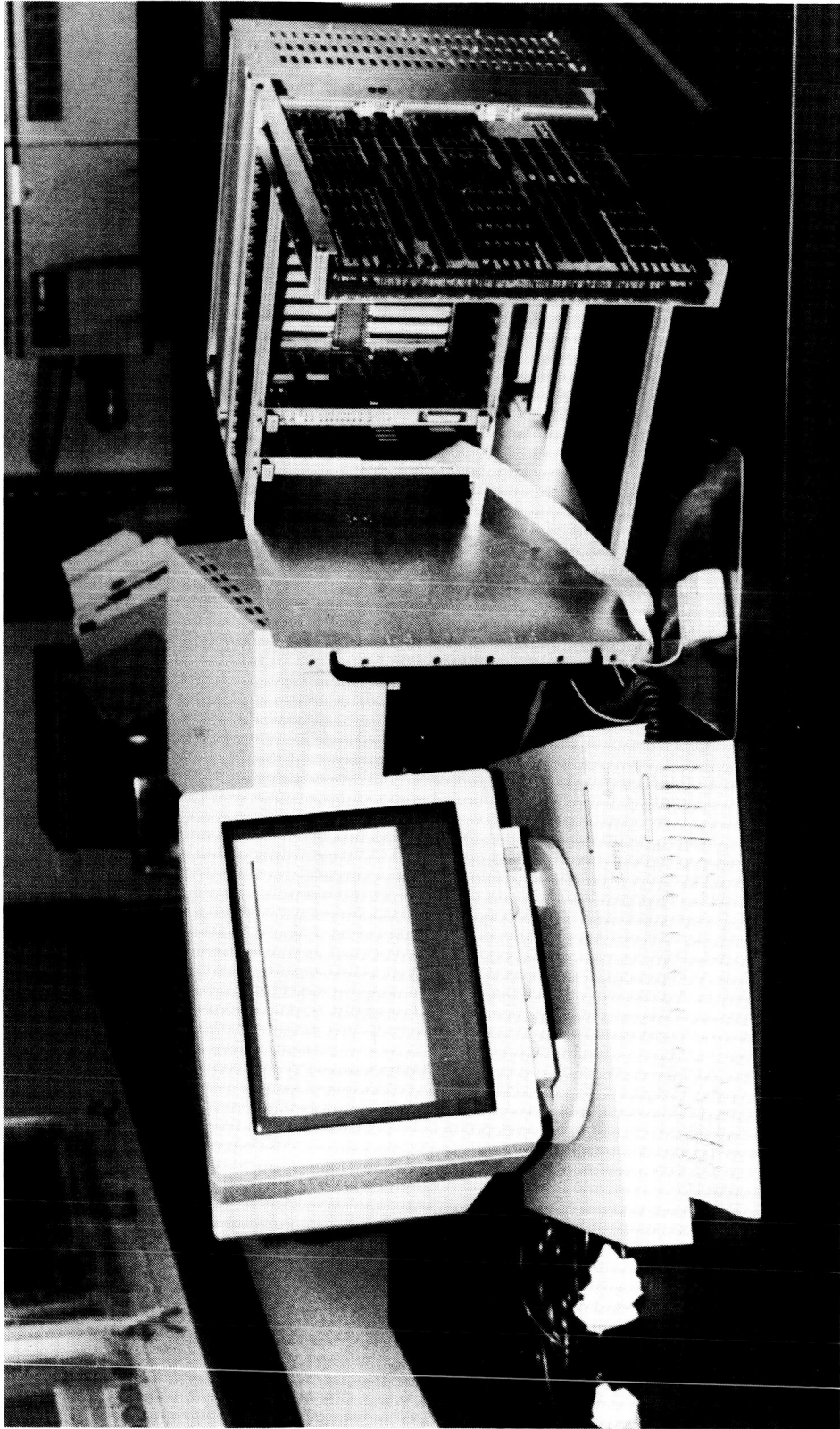
Sparse distributed memory is a massively parallel architecture motivated by efforts to understand how the human brain works and by the desire to build machines capable of similar behavior. SDM is a pattern computer designed to process very large patterns formulated as bit strings that may be thousands of bits long. Each bit string can serve as both content and address within the memory. Our model has four main components: 1) a "focus" that holds a large pattern of features representing a moment of the systems experience; 2) a sensory apparatus that extracts features from signals received from the world and feeds them into the focus; 3) a motor apparatus that is driven from the focus and affects the world; and 4) a long-term memory for large patterns that is connected to the focus and holds an internal model of the world built at least in part through experience. SDM is a member of the family of connectionist architectures. It differs from the related family of neural-net architectures because it is capable of storing very long pattern sequences as well as individual patterns. Therefore, the memory can store a dynamic model of the world that can be used for prediction based on experience. Ordinary computer memory (RAM) is a special case of Sparse Distributed Memory.

Three sources of natural data are under study: the reading aloud of English, the recognition of written characters, and speech recognition. In the reading project the memory is trained to translate written text into phonetic transcription; in the character-recognition project the memory is trained to identify characters. These "application studies" are carried out with memory simulators programmed for conventional computers. An SDM simulator has been written for the Connection Machine, and a digital prototype of sparse distributed memory, running as an attached processor on a Sun workstation, has been completed at Stanford and will be delivered to RIACS in the summer of 1988. A speech recognition laboratory incorporating the SDM prototype is near completion.

RIACS scientist Pentti Kanerva, inventor of the SDM, has completed a book about SDM, which is in press at MIT Press. Collaboration is underway with scientists from NASA Ames Information Science Division, Hewlett-Packard Laboratories, Stanford University, and the University of Nebraska.

TECHNICAL CONTACT: Michael R. Rough, ARC (415) 694-5402

**PROTOTYPE OF THE SPARSE DISTRIBUTED MEMORY
WHICH IS A MASSIVELY PARALLEL ARCHITECTURE MOTIVATED
BY EFFORTS TO UNDERSTAND HOW THE HUMAN BRAIN WORKS.
THE PROTOTYPE WAS BUILT BY STANFORD UNIVERSITY AND HEAVILY
UTILIZES STANDARD COMPUTER MEMORY PARTS.**



Spaceborne VHSIC Multiprocessor System (SVMS)

The Phase I design definition study effort for the Spaceborne VHSIC Multiprocessor System (SVMS) was completed during May 1988. The request for Proposal (RFP) for Phase II, detailed design and development of the SVMS brassboard, was released for competitive procurement on July 15, 1988 with an estimated Phase II start date during November 1988. Two competing Phase II efforts will be awarded with selection of one of the Phase II contractors for the Phase III effort: development, qualification, and delivery of the space-qualified system during early CY-95.

The SVMS Project is a joint development involving NASA/Ames, Air Force/Rome Air Development Center (RADC), and DARPA. NASA/Ames is responsible for the development of the parallel VHSIC symbolic processing system, the parallel operating system, and the system integration and interfaces for the numeric and symbolic processors. RADC is responsible for the development and delivery of the numeric processor (RH-32) to NASA/Ames. DARPA is sponsoring the development of the VHSIC modules used in the SVMS as well as the dynamic load scheduler used for the multiprocessor system. For the SVMS 0.5 μ rad-hard CMOS VHSIC technology is targeted, with 1.25 μ CMOS VHSIC technology as the alternate. The device technology process will ensure that there are no single event upsets when the SVMS is subjected to a radiation environment.

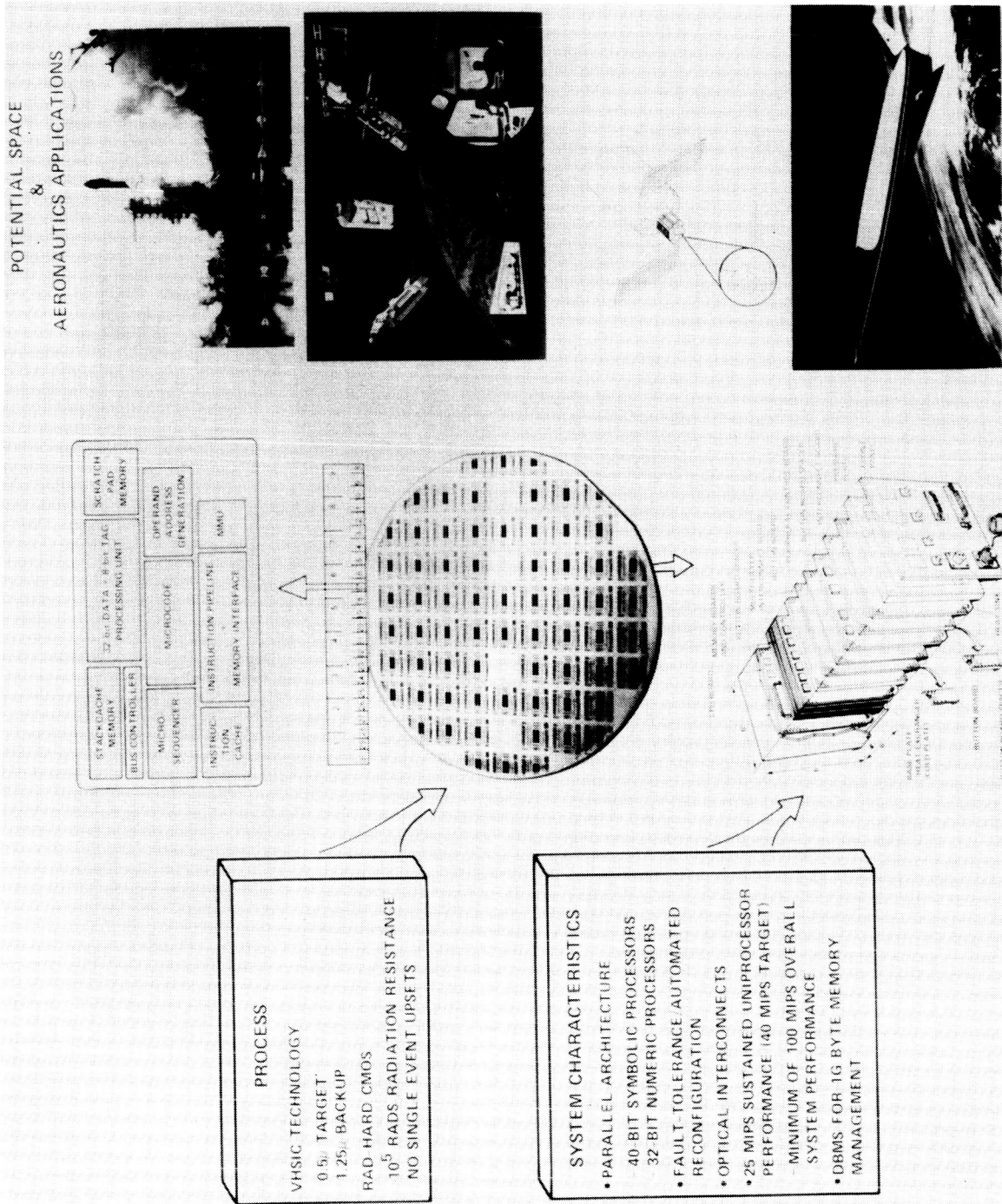
SVMS system characteristics include: parallel architecture consisting of 40-bit symbolic processors and 32-bit numeric processors; built-in fault detection, identification and recovery with automated reconfiguration of the processors and network to resolve detected faults; optical interconnects and cross-bars; 25 mips sustained uniprocessor performance with a target of 40 mips; minimum of 100 mips sustained system performance for 10 Gbytes memory management.

Applicable academic research efforts related to the SVMS include: (a) A dynamic load scheduler and real-time operating systems for parallel architectures (Ben Wah, University of Illinois); (b) Parallel real-time Ada compilers, and LISP-to-Ada translators (Richard Volz, Texas A&M).

The SVMS is compatible with the Space Station IOC schedule as well as the Air Force applicable mission schedules. The SVMS will provide the processing capability required to implement real-time knowledge-based systems for space flight applications that are not provided by current and/or projected near-term processors.

TECHNICAL CONTRACT: Henry Lum, ARC, (415) 694-6544

SPACEBORNE VHSIC MULTIPROCESSOR SYSTEM (SVMS)



The Goddard Space Flight Center (GSFC) has recognized the need to advance the state of the art of onboard high data rate signal processing for future generation scientific instruments and has chosen for this purpose to develop GaAs integrated circuit technology.

Key requirements in onboard signal processing instruments results from projected increases in information return from earth viewing instruments. Advancements in multispectral sensory will produce finer spatial resolution, greater spectral coverage, and consequently greater increased data rates and system bandwidth requirements. Feasibility studies on solid state imaging instruments in support of the Earth Observing Systems have shown increased rates that exceed the telecommunication channel capacity. Onboard signal processing will be necessary in order to utilize the available Tracking and Data Relay Satellite System (TDRSS) communication channel at high efficiency.

The technical approach taken is to develop an 8-bit slice GaAs processor chip set capable of performing high data rate image processing algorithms.

The 8-bit slice architecture is a cascadable processing element, specifically designed as a MIL-STD-1750A computer building block, but flexible enough for other applications, such as reduced instruction set computers (RISC) and signal processors. The initial application for the chip is a signal processing system performing a data compression algorithm.

Both the data compression controller and 8-bit slice were fabricated by Rockwell. High speed testing has demonstrated 150 million operations per second (MOPS) performance at a power dissipation of 9.2 W. A lower power version obtained by slightly varying the threshold level executes 100 MOPS at 4.2 W. The single chip worst-case delay paths are the register-to-register ALU add/subtract and the Program Counter increment; these are diagrammed in the figure. The operating waveforms show Memory Address outputs incremented by repeated register-to-register ALU adds. The clock rate is 150 MHz, indicating an operation every 6.6 ns.

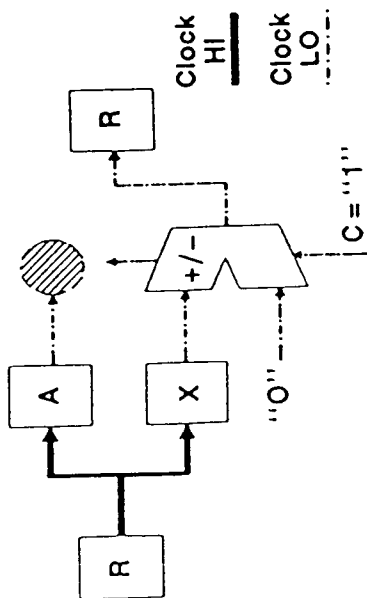
System testing to demonstrate image compression is projected for second quarter 1989.

TECHNICAL CONTACT: Warner H. Miller, GSFC, (301) 286-8183.

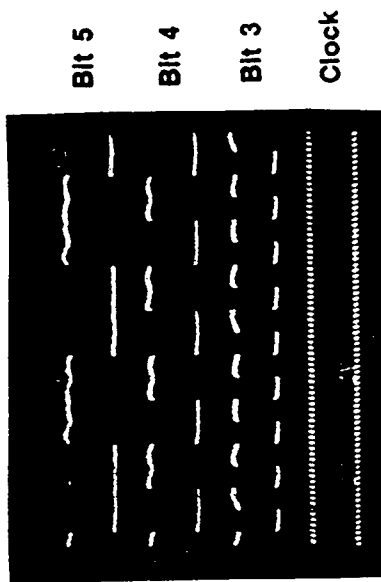
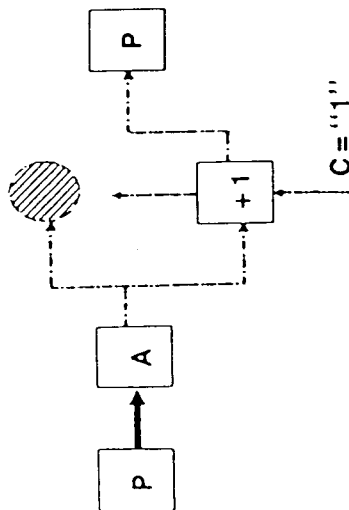
8-BIT SLICE PROCESSOR PERFORMANCE RESULTS

OASIT

Register to Register Add/Subtract



Program Counter Increment



Memory Address Output Oscilloscope Waveforms

ALU Adds Incrementing Register 0, at 150 MHz Clock

- * SINGLE CHIP WORST CASE DELAY PATH
6.6 NANOSECOND.
- * PROJECTED 1750 INSTRUCTION SET PERFORMANCE
APPROXIMATELY 3X VHSIC PHASE 2.
- * RAD HARD (100 M RAD) TOTAL DOSE.
- * PERFORM LOSSLESS COMPRESSION OF HIRIS IMAGE
IN REAL TIME WITH 25% TIME MARGIN.

MAX
High Performance General Purpose Computer for Space Applications

Future NASA missions will require general purpose computing performance well beyond the capabilities of systems in use today. This performance must be available with high efficiency and reliability, and should be versatile enough to meet a broad spectrum of needs. The objectives of the MAX program are to develop a general purpose computing architecture capable of meeting these requirements, and to implement and demonstrate this architecture in a form suitable for flight qualification. The resulting system, which has been dubbed MAX, combines a number of innovative features in a balanced design to address the important issues of spacecraft computing.

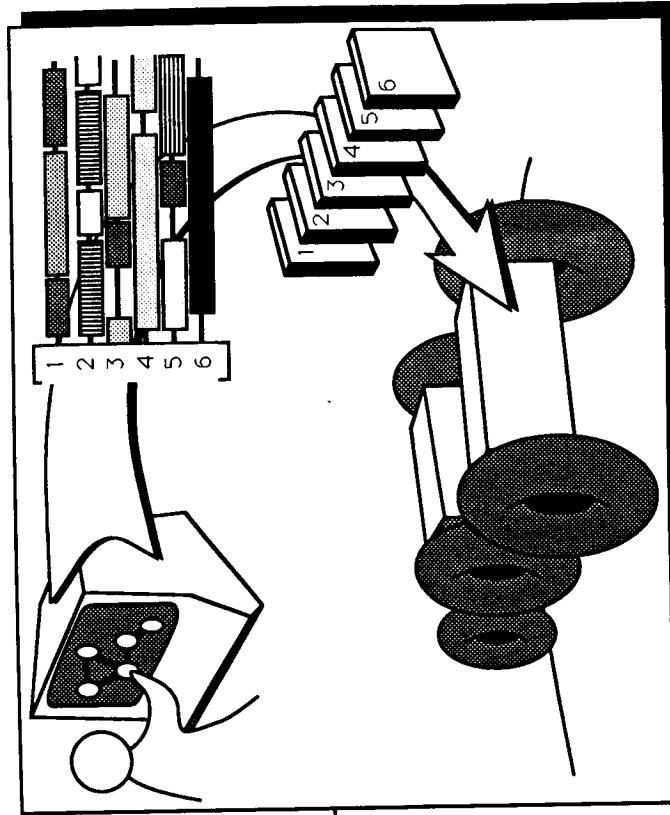
MAX is a parallel processing system comprised of one or more modules of one or more types. Any number of modules is allowed. The selection of interconnection technology is optimized for high performance and reliability at low power. Three custom VLSI devices have been designed for this purpose. Modules are interconnected to one another (and to peripheral hardware) via a dual, asynchronous, serial communication structure. Global broadcast busses allow fast, reliable coordination of module activities, while a high-speed circuit switched network handles rapid data exchange. Communication capacity grows as modules are added. Through a hierarchical distribution of control and programmable locality of coordination, the system can efficiently provide real-time responsiveness.

The MAX operating system supports conventional multitasking as well as a parallel, coarse grain, data flow model. This tagged token model, with elaborate firing rules, a hierarchical graph structure, reentrant subgraphs, and the unique use of token encapsulated code, provides a powerful paradigm under which concurrent, real-time programs can be developed with ease. In addition, the model provides software implemented fault tolerance based on token comparison and a transaction model of execution. The data flow token provides a unifying mechanism for many fundamental system operations, resulting in a robust design. Data flow programs are prepared using a conventional high-level language in conjunction with an interactive graph compiler for the preparation and testing of data flow graphs.

The MAX program has advanced to the completion of a breadboard design based on SA3300 radiation hard technology from Sandia National Laboratories. One module has been fabricated and tested with discrete emulations of custom VLSI devices. Several additional modules are in production in preparation for multi-module tests. The data flow operating system, which has been tested in simulation, is undergoing tests on breadboard hardware. The graph compiler is operational for textual data flow graph descriptions; graphical interface implementation is near completion. Future plans involve the completion of VLSI devices, refinement of the operating system and software tools, and the development of sample applications to exercise and demonstrate the system. Future implementations in higher speed VHSIC technology are also planned.

TECHNICAL CONTACT: Robert Rasmussen, JPL, (818) 354-2861

MAX DATA FLOW MODEL



• Dataflow provides a unifying design paradigm

- software modularity
- concurrency
- communication
- load balancing
- memory allocation
- fault tolerance

• Resources assigned dynamically:

- processing power
- memory
- communications

• All resources applied to the task at hand \Rightarrow high efficiency

• Graceful adaptation to loss of resources \Rightarrow fault tolerance

Digital Autocorrelator Spectrometer

The objective of this program is to develop a prototype digital spectrometer, using VLSI technology, which will have a small size, low power requirements and can be used in spacecraft mm and submm radiometer systems.

OAST funds an ambitious development program for applying heterodyne techniques for remote sensing of the Earth's atmosphere and for planetary and astrophysical observations. The program for Earth atmospheric observations using mm- and submm-wave spectral line radiometers includes the Balloon Microwave Limb Sounder (BMLS), the Microwave Limb Sounder on UARS, and a planned system for the Eos. There is also an airborne astronomy program on the KAO and there are proposals to fly Scout mm- and submm-wave radiometers, the Submm Explorer Telescope, and the Large Deployable Reflector (LDR) for astrophysical observations.

Three general approaches are used for spectrometers: (1) filter banks, (2) acousto-optic spectrometers (AOS), and (3) digital autocorrelators. The filter banks are the most commonly used because of their simplicity; however, for spectrometers with greater than 100 channels, their size, weight, and power make their use for Space instruments very undesirable. The AOS is an optical processing approach in which a laser beam is diffracted from acoustic waves in a piezoelectric crystal and detected on an optical array. The AOS has recently come into use in a few radio astronomy observatories. However, there are questions on their temperature stability, and the laser reliability. In contrast to the two frequency domain techniques described above, the autocorrelator works in the time domain. The digital autocorrelator has been used in many radio astronomy observatories for many years and is a proven method for radiometer spectrometers. The disadvantage of present laboratory autocorrelators for space applications is that they have been constructed with medium-scale digital integrated circuits which involves a large number of parts and consumes considerable power. However, with the latest developments in super computers and VLSI, it is now possible to plan the technology development of a very low power and small digital autocorrelation spectrometer.

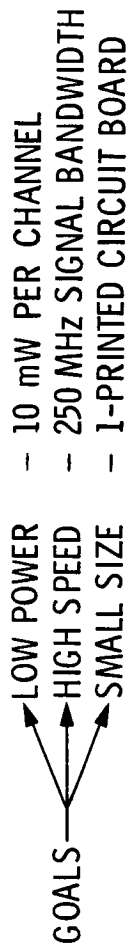
In FY88, a 26-channel two-bit autocorrelator gate array VLSI chip was developed and incorporated into a prototype 52-channel autocorrelator. This autocorrelator has a clock speed >100 MHz and required 120 mW/channel. In FY89, it is planned to completely test this autocorrelator and characterize its performance and limitations. Also, a design for very low power (VLP) (<10 mW/channel) autocorrelator will be studied. This design will be for a narrow band spectrometer and may use CMOS technology.

TECHNICAL CONTACT: William Wilson, JPL, (818) 354-5699

AUTOCORRELATOR SPECTROMETER

TECHNICAL GOAL: DEVELOP WIDEBAND MULTICHANNEL SPECTROMETER FOR SPACEFLIGHT
WITH LOW POWER, SMALL SIZE/WEIGHT AND HIGH RELIABILITY

TECHNICAL APPROACH: USE VLSI GATE ARRAY AUTOCORRELATOR CHIP



ENABLING TECHNOLOGY FOR
FUTURE PROGRAMS:

AIRCRAFT — KAO (C-141)

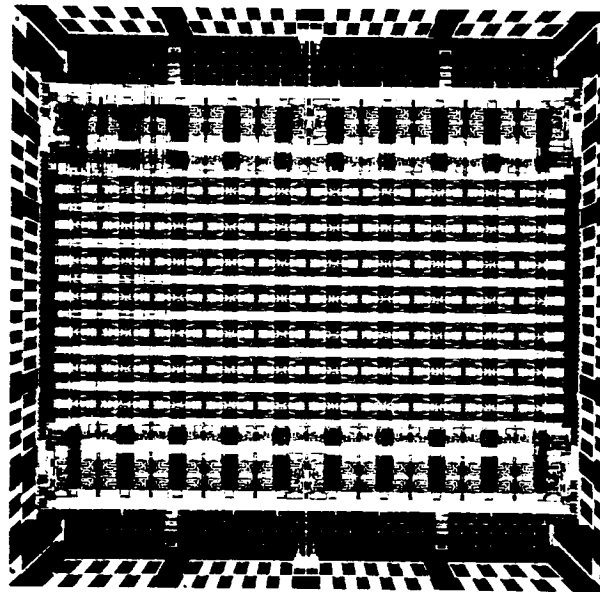
BALLOON — (MLS)

SPACECRAFT

— EOS (EMLS)

— SUBMILLIMETER EXPLORER

— LARGE DEPLOYABLE REFLECTOR



GATE ARRAY CHIP

Flight SAR Processor

The objective of this program is to design and develop an onboard SAR processor that will meet the needs of the Eos SAR Mission. The technology and techniques necessary to accomplish the goal of onboard SAR data processing are under development. The science and operational requirements for the Eos SAR are currently being clarified and established.

Onboard SAR processing is a very challenging technical problem. The SAR instrument will collect enormous volumes of raw SAR data. In order to process the raw SAR data into imagery in real-time the processor must be capable of operating at very high speed. A first step in attacking the problem was the successful demonstration of the JPL Advanced Digital SAR Processor (ADSP) in 1986. ADSP is a 6 GFLOP processor capable of providing SEASAT and SIR-B imagery in real-time. The ADSP, although entirely successful, falls short of providing the technology required for real-time onboard processing of SAR data since it occupies two 7-foot racks and consumes a total of 20 KW.

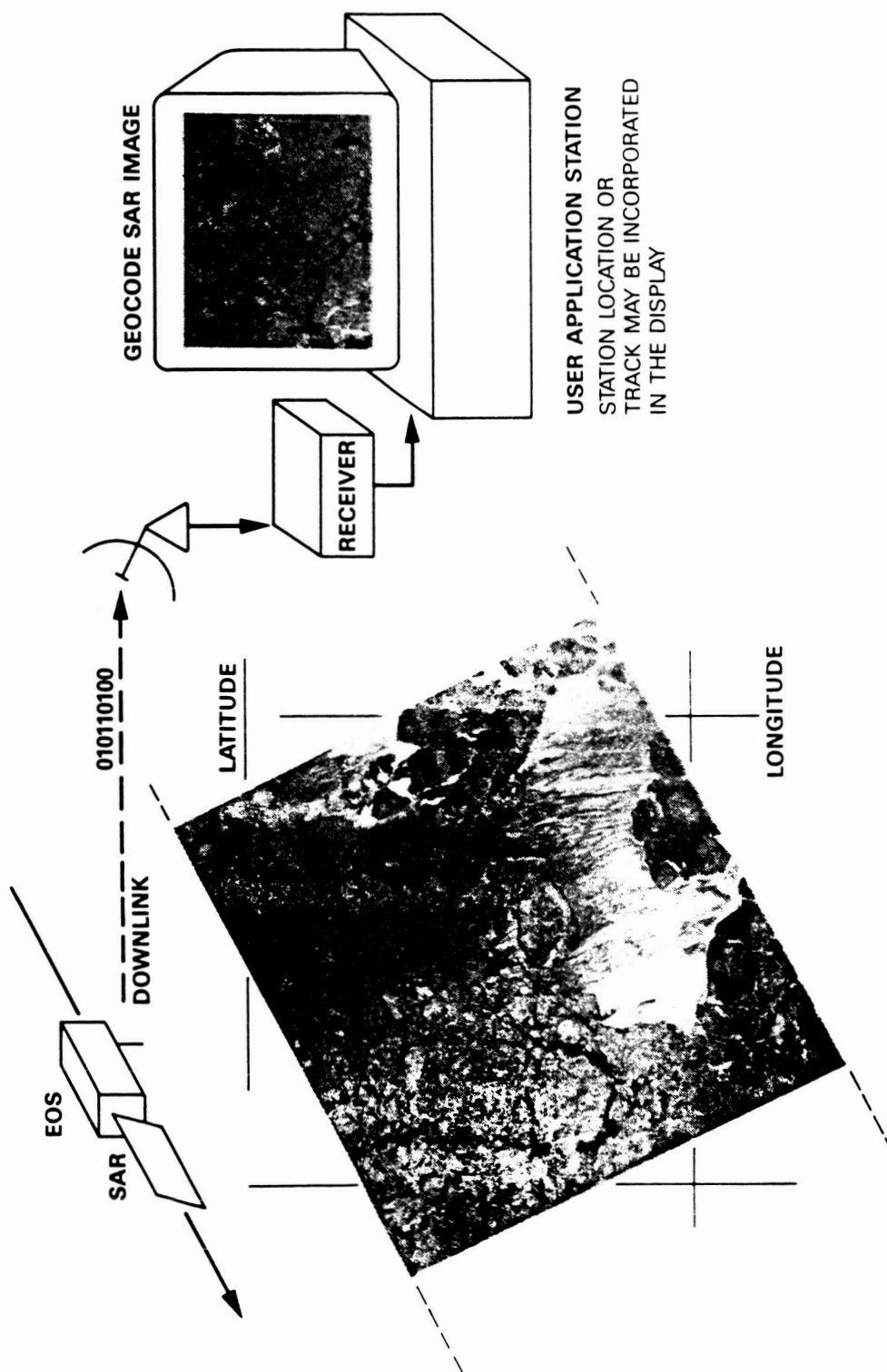
In addition to real-time processing of the raw SAR data, the onboard processor will enable the use of data compression to mitigate the data rate and volume problems imposed upon the TDRSS downlink. For those users who require image data in near real-time, onboard SAR processing would enable direct downlink of the onboard generated images. In both cases the onboard processor will reduce the SAR data rate and make the transmitted information more immediately useful.

Requirements for the onboard SAR processor are currently being evaluated. On the basis of the requirements, several candidate architectures will be developed. Ultimately, one of these architectures will be chosen based on a trade-off analysis. The identification and development of technologies to support the onboard SAR processor is continuing.

TECHNICAL CONTACTS: Conrad Wong, JPL, (818) 354-5300
Mike Henry, JPL, (818) 354-0915

CONCEPT OF EOS ON-BOARD SAR PROCESSOR OPERATION

OST



Imaging Spectrometer Flight Processor Technology

Imaging spectrometer instrument technology is now capable of providing spaceborne multispectral imaging systems producing data at peak rates in excess of 500 Mbits/sec. Given the constraints imposed by available telemetry channel capacities, new approaches utilizing very high-speed computational hardware and novel processing algorithms need to be developed for data compression and information extraction operations onboard the instrument platform. The science utility of imaging spectrometer data lies in the spectral resolution capabilities of the instrument, i.e., the ability to observe relatively narrow spectral reflectance features, and onboard processing and data reduction strategies must both make use of and preserve the spectral information content of the data.

The objectives of this technology development task are threefold: (1) Development and demonstration of processing architectures capable of performing focal plane array data correction operations, such as gain/offset and radiometry, at real-time instrument rates; (2) Development and demonstration of both lossless and lossy data compression technology suitable for high-rate imaging spectrometer class instruments; and (3) Development and demonstration of computational technology for direct onboard information extraction of scientifically meaningful geophysical and biophysical parameters. The objectives support the overall goal of maximizing the scientific utility of spaceborne imaging spectrometry for both near-earth and planetary exploration missions. The work carried out within this task maintains close contact with other technology development tasks such as GaAs processor technology (Goddard Space Flight Center), and DoD-sponsored work such as VHSIC and GVSC.

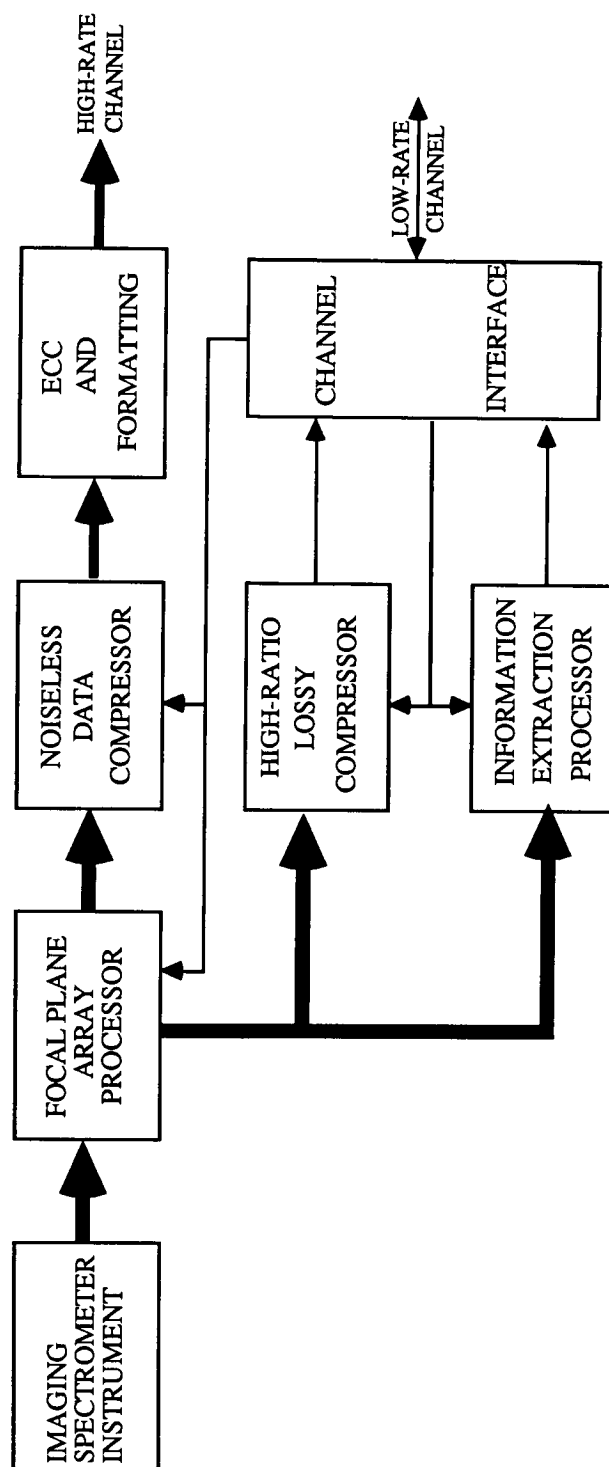
During the first year of this work, a design for real-time focal plane array processing, utilizing space qualifiable hardware, has been completed and fabrication of a laboratory demonstration breadboard has begun. This breadboard will be used for design validation and for extension of the technology to a flight breadboard demonstration system. A conceptual design for a 1.5 μ m CMOS VLSI implementation of a noiseless data compressor, capable of functioning at single-channel rates of about 40 Mbits/sec, has been completed. During the coming year, this design will be used to produce prototype chip set for laboratory validation; results of this work will lead to fabrication of a flight prototype demonstration compressor system. Initial studies on vector quantization methods applied to high-ratio lossy compression of imaging spectrometer data have been completed; these studies indicate the potential for 50:1 compression of this data type, while preserving much of the information required for science analysis. Definition of a subset of scientifically meaningful onboard information extraction operations has been completed utilizing input from the remote sensing science community. These operations have been used to develop a set of candidate algorithms for onboard data reduction processing, and to develop an initial conceptual design of a special purpose computational architecture for this processing.

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IMAGING SPECTROMETER FLIGHT PROCESSOR

—OAS—

CONCEPT



Algorithm to Architecture Mapping Model (ATAMM)

The objective of this research was to develop a theory-based methodology for the real-time assignment of nodes of a directed graph algorithm to concurrently operating processors for throughput and fault-tolerance enhancement in future spaceborne flight computers.

A data flow graph management methodology is being developed and its performance is to be tested in a Very High Speed Integrated Circuit (VHSIC) four-processor breadboard system. Graph management employs both the forward flow of data and backward flow of control information to make dynamic assignment of algorithm nodes to one of many concurrent processors. Each processor has the identical software to perform all of the algorithm nodes. Modeling and simulation capabilities are developed and applied to predict the dependence of concurrency performance on node interconnection complexity and node granularity. Modeling efforts are based on Petri Net theory and are initially limited to event driven decision-free graphs similar to many flight control algorithms.

A model of the graph management concept, Algorithm to Architecture Mapping Model (ATAMM), has been accomplished. It provides the rules for assigning graph nodes to processors in a parallel architecture. When applied to a specific directed graph algorithm, ATAMM predicts: 1) the maximum attainable throughput rate; 2) the number of concurrent processors needed to attain the maximum throughput; and 3) the dependence of maximum throughput on the number of available concurrent processors. The model is presently hardware-independent and essentially gives the maximum performance based on the interconnect characteristics of the directed graph and the node time duration. Performance margins for a few simple algorithm graphs have been generated.

The realization of ATAMM has shown the real-time dynamic node assignment concept to be theoretically feasible. ATAMM provides a new capability to predict performance bounds of application algorithms and could become a major tool for the design and development of application algorithms. Ultimately this concept should provide a method of mixing application goals of throughput enhancement and user-selectable fault tolerance in the same system.

In the future ATAMM will be used to explore the classification of algorithm types according to performance bounds. Candidate algorithms will be analyzed and optimized for hardware evaluations. The hardware performance results will be used to verify and/or refine ATAMM. Future development of ATAMM will focus on processor labeling, system processor and bus parameters, and decision type graphs.

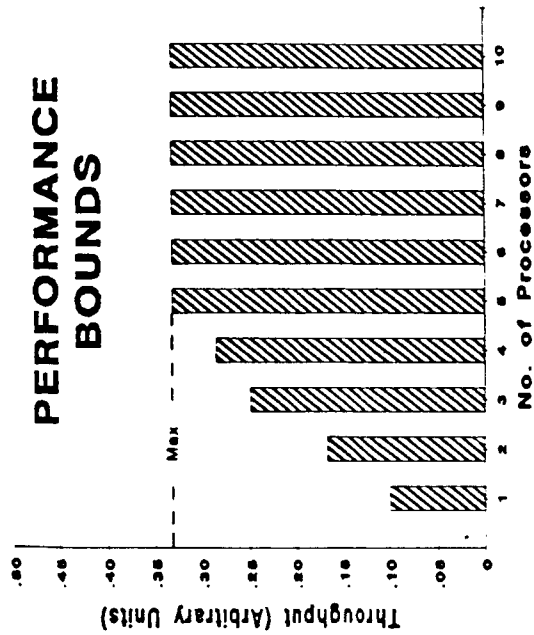
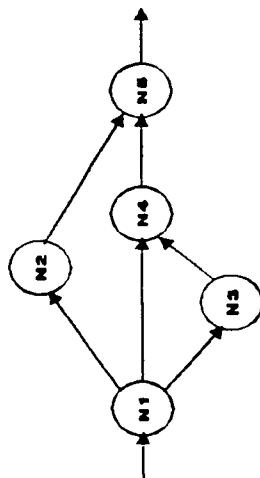
TECHNICAL CONTACT: Paul J. Hayes, LaRC, (804) 864-1491

ALGORITHM TO ARCHITECTURE MAPPING MODEL (ATAMM)

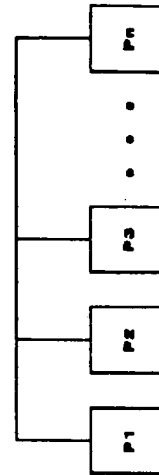
LaRC / OLD DOMINION UNIVERSITY

OA-ST

ALGORITHM GRAPH



MULTIPROCESSOR



FEATURES

- Decision-free graph
 - Node Latency
 - Graph Interconnect
- Performance Bounds
- Petri Net Theoretical Base

Human Factors - Aeronautics

The objectives of the aeronautics human factors research and technology program are to provide the technology base and capability to design effective crew-cockpit systems and to advance solutions to human problems affecting air transport and rotorcraft effectiveness and safety. Advanced automation technologies, new information display capabilities under computer control, and concern for the effects of human error in flight operations are elements that drive the directions of the program. Thus, the program has four thrusts: (1) flight management; (2) human engineering methods; (3) rotorcraft; and (4) subsonic transports.

Flight management research is aimed at development and evaluation of methods and techniques that allow the crew to deal with various problems in the flight environment. An expert system called Faultfinder was developed and is being evaluated to allow early detection of engine failures and to recommend to the crew alternatives in power management for safe operations. Studies were completed that established the minimum amount of information to be displayed to the pilot in an advanced tactical aircraft. Additional research was performed on an advanced, three-dimensional display method that shows a path in the sky to be followed for different flight regimes.

Human engineering research has had a long-term objective to implement state-of-the-art psychophysiological response measurement methods as an aid in crew workload assessment. Several studies were completed that resulted in an improvement in sensitivity whereby heart rate variability is measured during various types of flight operations. Workload associated with low demands on the pilot result in boredom. This mental state was measured and evaluated by a new psychophysiological model.

Rotorcraft research focused on the different kinds of human visual requirements for effective nap-of-earth (NOE) operations and the subsequent design considerations for helicopter operations and displays. Studies were performed on workload and operational tasks of pilots involved in unusual rotorcraft operations, such as police surveillance and medical evacuations. A data collection program was initiated to gain data in an attempt to understand and deal with the high number of incidents and accidents in these types of operations.

Subsonic transport research, including commuter and general aviation, is intended to develop and evaluate technologies that the crew can use to detect and successfully avoid/escape wind shear hazards. Data on wind shear statistics, structure and severity were collected and used to develop and evaluate flight guidance techniques for recovery and escape. Concepts for the display of wind shear information and route of recovery and escape were identified as well and simulation data was obtained to further guide display development.

Extensive plans have been prepared and coordinated between Ames Research Center and Langley Research Center for a new initiative, called Aviation Safety/Automation, which will start in FY89. Its objective is to focus results of the

existing baseline research in order to improve the national airspace transportation system capacity and safety and to demonstrate and transfer effective technology to the national aviation community. This technology will allow optimal integration of humans and automated systems, provide human-centered automation in air traffic control and flight systems, and support and improve human capabilities through fully compatible cooperative air-ground systems.

PROGRAM MANAGER: Dr. James P. Jenkins
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TCAS: Traffic-Alert Collision Avoidance System

TCAS is a stand-alone system that can detect the presence of any transponder-equipped aircraft that is within a prescribed envelope around a TCAS-equipped aircraft. TCAS can provide the pilot with a visual display showing the relative position, distance and altitude of other aircraft. TCAS evaluates the closure rates and flight geometry of other aircraft relative to itself. If TCAS calculates that a collision threat exists it will issue visual and verbal maneuver commands to the pilot. TCAS can "see" other aircraft even though the pilot may not be able to, such as in conditions of reduced visibility or high workload.

The Aviation Industry looks to NASA Ames for guidance in evaluating the many human factor issues such as:

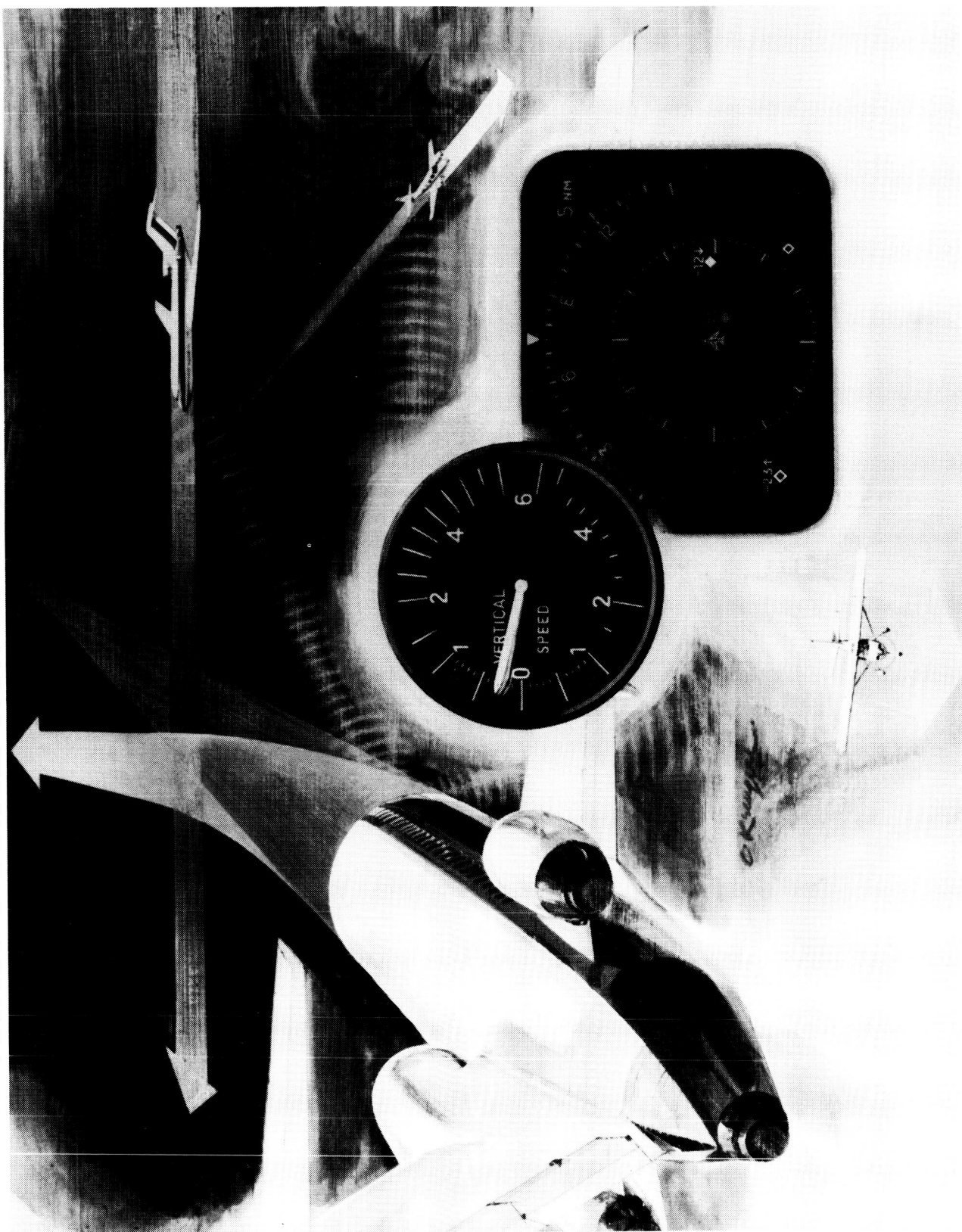
- 1) pilot interpretation of the information that TCAS makes available;
- 2) pilot acceptance of the display format chosen by the manufacturers;
- 3) pilot willingness to trust a system that commands him to make sometimes abrupt evasive maneuvers due to unseen traffic;
- 4) pilot response time and success rate;
- 5) system configuration changes introduced by industry; and
- 6) integration of TCAS into the routine operating environment already existing in the cockpit.

NASA Ames Research Center has conducted TCAS experiments using currently working airline crews flying typical airline flights to both terminal metropolitan destinations and outlying airports. These experiments explored: 1) TCAS with part-time and full-time traffic display and with no traffic display (just maneuver information); 2) pilot performance with and without target areas displayed on the vertical speed indicator; and 3) pilot execution of the commanded maneuvers in different aircraft performance regimes. As an indication of industry involvement two of the nation's major airlines currently have a limited number of TCAS equipped aircraft operating on routine daily flights within the national airspace system.

Future research now planned will explore optimization of TCAS maneuver guidance for the "glass cockpit," combining traffic with navigational information, and optimization of the voice command vocabulary to elicit proper pilot response.

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ARTIST'S CONCEPTION OF TCAS ENCOUNTERS



Evaluation of a Prototype Diagnostic Expert System Using NTSB Accident Cases

A research prototype of an onboard fault monitoring and diagnosis expert system has been developed to demonstrate the use of artificial intelligence techniques in providing aid to the flight crews of civil transport aircraft. This prototype, called Faultfinder, detects and provides diagnoses of failures in the engine and hydraulic subsystems of a generic aircraft. The diagnosis process is performed in two stages. The first stage uses rules to diagnose known faults. The second stage uses model-based reasoning to diagnose faults that were not included in the rules. The objective of this effort was to evaluate the performance using data from actual aircraft accident cases. Specifically, the objectives of this evaluation were to perform a preliminary assessment of the performance of the expert system, to determine the validity of the concept, and to identify future areas of research and development.

Eight accident cases obtained from the National Transportation Safety Board (NTSB) were selected to evaluate Faultfinder. First, these cases were reconstructed to produce a simulation of the accident. Next, the expert system was run using the simulations to produce hypotheses for the probable cause of the failure for each test case. The hypotheses produced were then compared to the correct diagnosis of the failure as determined by the NTSB. Finally, the results of this comparison were analyzed to assess the system performance.

The results of this evaluation showed that the implementation was able to correctly diagnose seven of the eight test cases that were reconstructed. As the accompanying figure shows, the first stage of the diagnosis process correctly diagnosed two of the eight test cases, while providing a partial diagnosis for a third. The partial diagnosis described a portion of the fault's effects. The second stage correctly diagnosed seven cases. In several cases, multiple hypotheses were produced. Such situations may result in ambiguity in the selection of the appropriate response by the flight crew. Enhancements to the knowledge base and inference structures are expected to reduce the number of multiple hypotheses. The evaluation demonstrated that the concept has potential for providing onboard aid to the flight crew in performing fault diagnosis.

This preliminary evaluation demonstrates that Faultfinder has potential for diagnosing failures, which in the past have resulted in serious aircraft accidents. These diagnoses may allow the flight crew to respond to a failure more quickly and more appropriately, which may result in reduced losses of life and property.

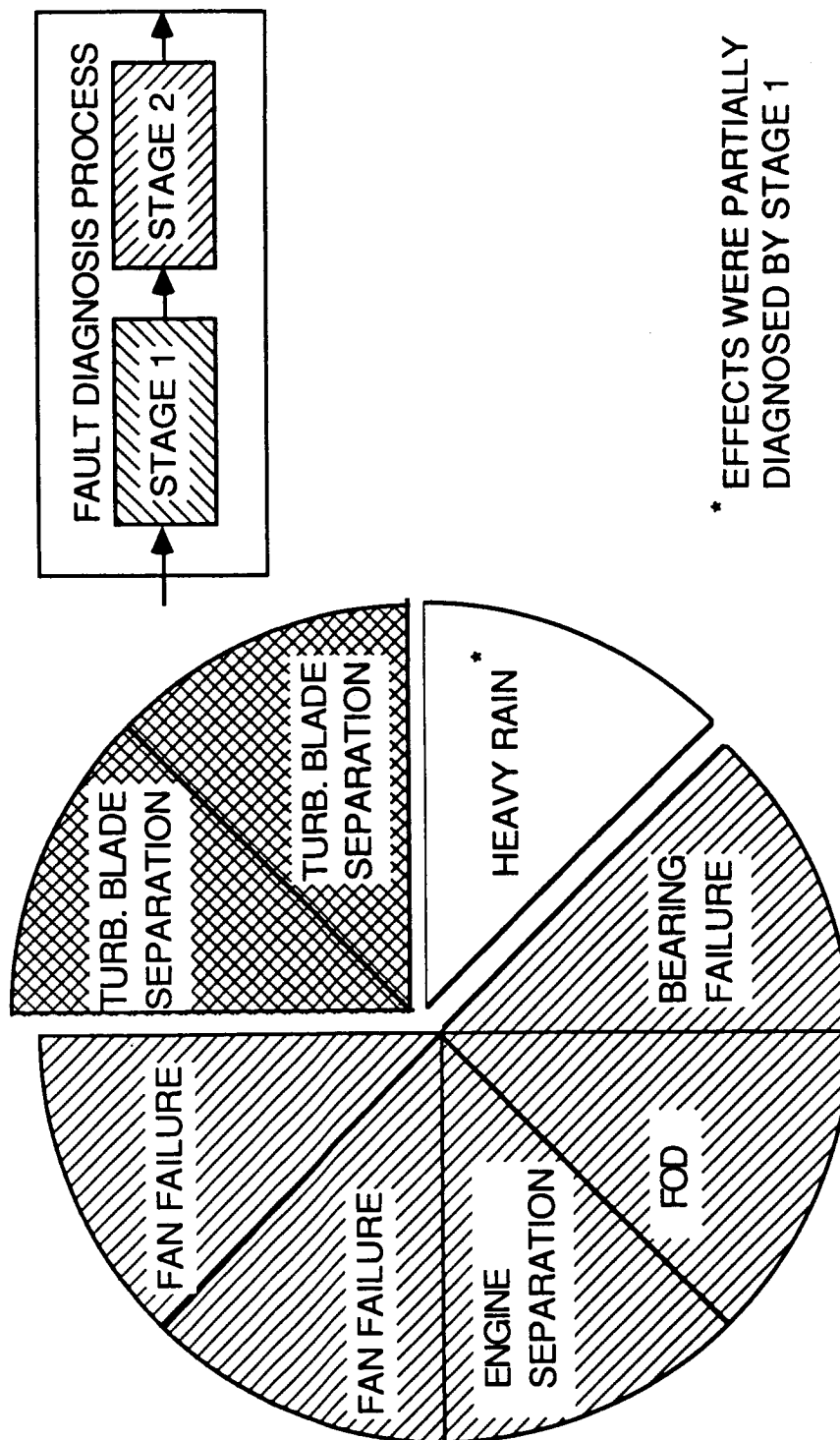
Refinements and additions to the implementation based on the results of this evaluation are planned. Research issues still exist in the area of interface between the expert system and the flight crew. Piloted simulation studies will be used to explore these and other issues.

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FAULTFINDER ACCIDENT-DIAGNOSIS CAPABILITY

CAST

(REPRESENTATIVE ACCIDENT SAMPLE)



* EFFECTS WERE PARTIALLY
DIAGNOSED BY STAGE 1

Intelligent Decision-Aiding Concept for ATC Diversions Demonstrated

A current problem in flight operations is the excessive pilot workload required while responding to flight plan diversions during critical flight phases. The objective of this research was to develop concepts and guidelines for applying Artificial Intelligence (AI) techniques for reducing pilot workload while generating new or revised flight plans, and to integrate these AI techniques into current and future flight management systems. This task is being performed by Lockheed Aeronautical Systems Company under contract as part of the Intelligent Cockpit Aids effort.

Through surveys of airline crews, concepts and candidate functions for an airborne crew decision aid for flight plan diversions were investigated. Available AI tools and architectures were reviewed, and a systems design was implemented as a research prototype, DIVERTER, on a Symbolics LISP machine. DIVERTER provides decision information to the crew regarding alternate airfields and routes based on weighted factors such as weather, safety of operations, economy, schedule, and facilities. Exploratory research is being conducted through a series of prototype states in which knowledge bases are expanded and crew and other onboard systems are integrated.

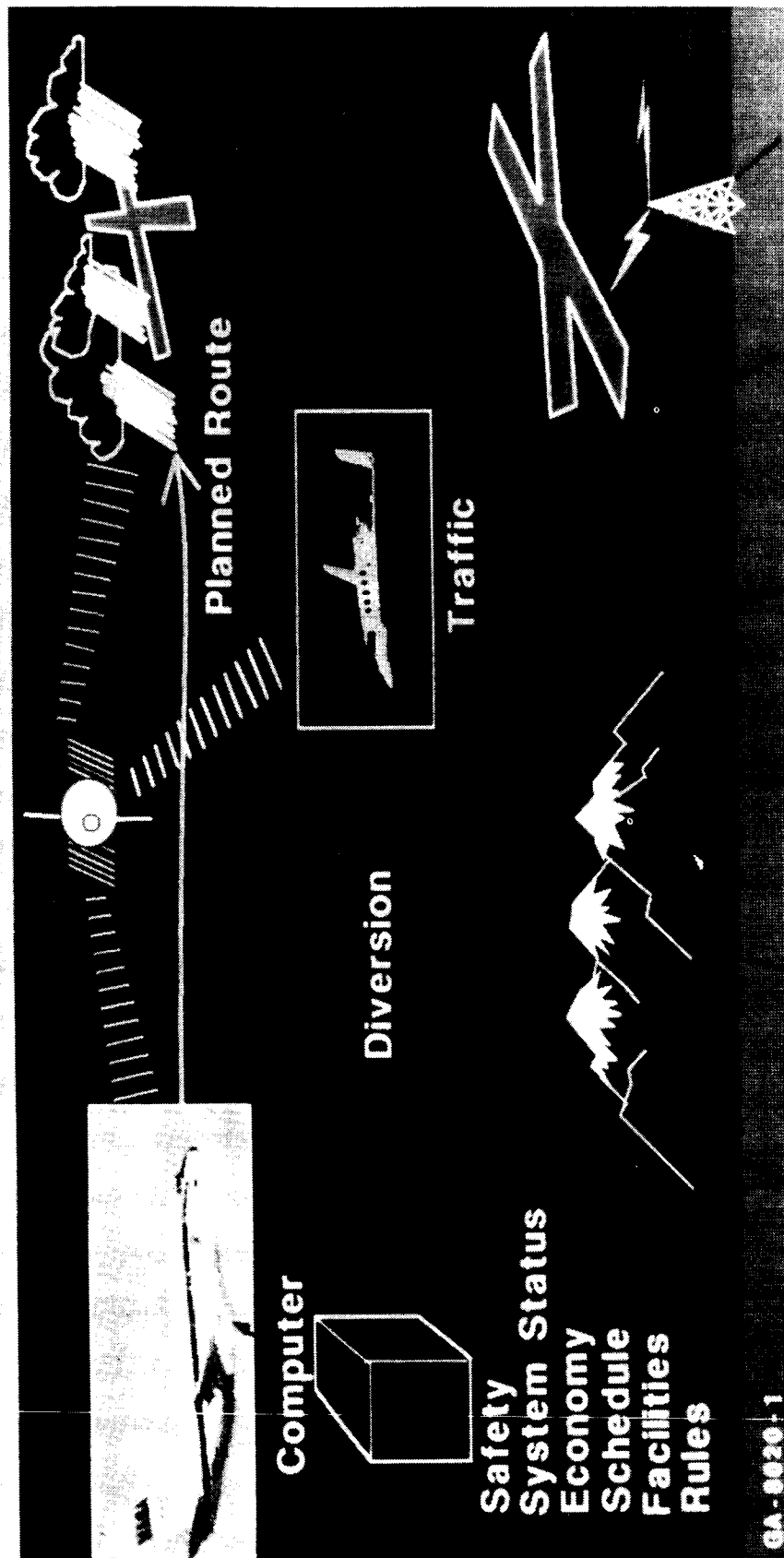
Two separate demonstrations of the research prototype DIVERTER system have been accomplished. The first demonstration included a skeletal system architecture based on a blackboard concept, with a relatively simple rule-based system to represent the decision logic. The system was demonstrated to accept a severe weather message that necessitated a diversion, and then to select and rank the available alternate airfields. Predetermined map displays were provided on the Symbolics terminal screen to show the user the change in route to the airfield he chose. The second demonstration, instead of using a set of predetermined routes to alternate airfields, planned these routes through the High-Altitude Jet Airway system using an AI search technique called A-Star. This planning was conducted with the additional factor of altitude necessary for passage through mountainous terrain.

This research effort demonstrated the feasibility of decision aiding for flight plan diversions. It provided a research prototype system, DIVERTER, which has been demonstrated to select and rank alternate airfields. DIVERTER also plans the best route to the chosen airfield considering the airway system, topography, weather, safety of operations, and economy. Expected benefits are enhanced flight safety and a reduction in peak crew workload.

During the next phase of this task, the pilot/vehicle interface of the DIVERTER prototype will be developed, and the prototype will be integrated into the Advanced Concepts Simulator at NASA Langley for future studies. Flight tests aboard the ATOPS TSRV B-737 aircraft are also planned.

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Diverter - Decision Aiding for Diversions



Individual Crew Factors in Flight Operations

The focus of this program is to assess the impact of fatigue and circadian rhythmicity on flight crew performance and to determine the contribution of factors associated with operational parameters, individual differences, and crew behavior. The approach is to combine limited laboratory and simulator research with an extensive set of field studies documenting the physiological and behavioral responses of aircrews operating in a variety of flight environments.

This is the first major attempt to objectively study these issues in both commercial and military flight crews. Increasing pressure for smaller and more productive crews requires a better understanding of how and why pilot performance can be degraded. Another driver is the planned introduction of highly automated aircraft into the long-haul arena. By fully understanding the impact and operation of these factors, it will be possible to improve flight safety and efficiency by: a) developing guidelines for rulemaking and aircraft certification; b) designing individual pilot coping strategies; and c) making operational recommendations to air carriers.

FY88 research has concentrated on field studies using cockpit observers and continuous physiological monitoring in several types of flight operations: 1) multisegment international long-haul patterns (B747 and USAF C141); 2) overnight cargo delivery (B727); and 3) extended range North Sea helicopter transport (4 rotorcraft types). Additionally, a cooperative program with research organizations and airlines in West Germany, the United Kingdom, and Japan has enabled the collection of EEG sleep data during layovers on eastward and westward polar routes through Anchorage for comparison with home recordings made before and after the trips.

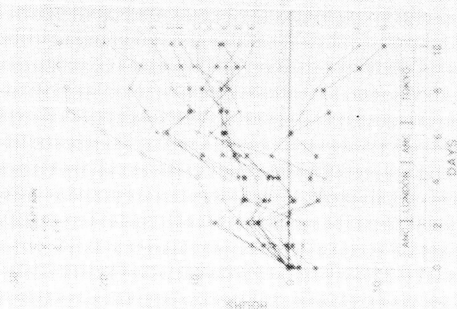
Data collection has been completed on long-haul crews, North Sea helicopter crews, and international polar crews. Reports and scientific publications are in various stages of preparation. Technology transfer to the industry is occurring through interaction with the FAA aircraft certification teams, two U.S. Pacific carriers, and the development with a U.S. manufacturer of a crew alertness support device for long-haul glass cockpits. Negotiations are underway for a full-mission long-haul simulation study and an inflight EEG study of preplanned cockpit napping to be initiated in Fall '88.

TECHNICAL CONTACT: R. Curtis Graeber, ARC (415) 694-5792

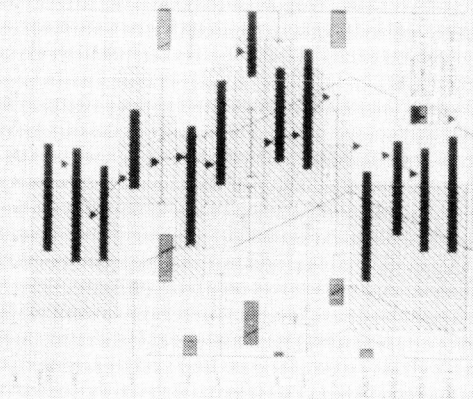
INDIVIDUAL CREW FACTORS IN FLIGHT OPERATIONS

Lufthansa

POLAR ROUTES: CUMULATIVE SLEEP LOSS



SINGAPORE TRIP PROFILE



FINDINGS

LONG-HAUL OPERATIONS

- INT'L COOPERATIVE POLAR ROUTE EEG STUDY – OUTBOUND DIRECTION CRUCIAL (EASTWARD WORSE)
- LARGE INDIVIDUAL DIFFERENCES IN SLEEP LOSS – DESIGN/OPS IMPLICATIONS FOR 2-PERSON COCKPITS
- SCIENTIFIC SCHEDULING GUIDELINES DEVELOPED

OVERNIGHT CARGO

- CAN PROVIDE UNIQUE INSIGHTS INTO CIRCADIAN DISRUPTION OF FLIGHT CREWS

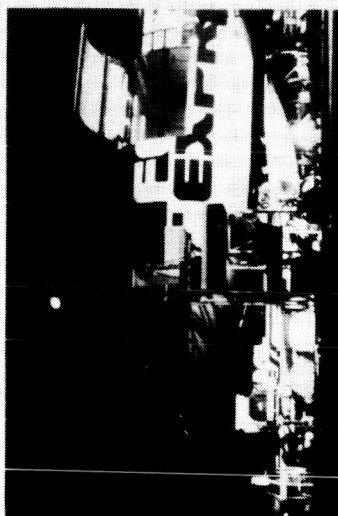
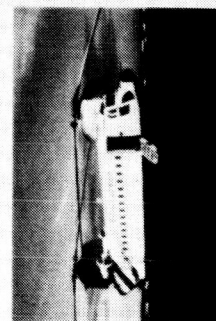
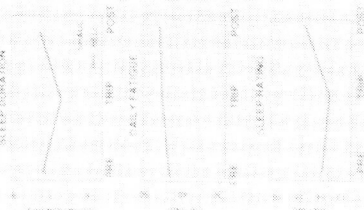
N. SEA HELICOPTERS

- DAILY SLEEP LOSS SIMILAR TO SHORT-HAUL BUT POORER SLEEP AND GREATER FATIGUE

PILOT SELECTION

- IMPROVED SELECTION STRATEGIES ARE FEASIBLE

HELICOPTER AND SHORT-HAUL PILOT POPULATION COMPARISONS



British airways

PAN AM

Improved Flight Training Procedures

As the complexity of civil and military rotorcraft and their range of operational environments continue to increase, traditional training methods become less appropriate and training time and costs escalate. Thus, the need for more cost-effective procedures has become critical. Although it is clear that not all skills require the same level of physical fidelity for training devices nor the same training philosophy, decisions about which methods are most appropriate for specific skills are based on tradition rather than scientific principle. The use of special-purpose computer "games" has been proposed as one method of reducing training costs. Computer games are inexpensive, intrinsically motivating, and can require some of the same skills used in flying. However, the degree to which skills learned in this context generalize to flight training has not been determined.

The goal of this program is to identify the most efficient and effective methods of improving flight-related skills. A variety of training procedures have been evaluated to determine the situations in which they will, and will not, be successful. One approach, that of using computer "games" to develop more efficient learning strategies and time-sharing skills, has received particular attention. The rationale is that some of the skills normally acquired during flight training could be developed through exposure to a carefully constructed "game" that is structurally, rather than physically, similar to the task of flying.

An operational test of the concept was performed by researchers from the Technion in the Israeli Air Force Flight School funded by a NASA grant. One training method was given to each of three groups of 20 Israeli Air Force Pilot-trainees matched on the basis of selection test scores. The experimental group received 10 hours of training on the game with specialized instruction to aid pilots in generalizing their game experience to flight school. The two control groups received either no game experience at all or played the game without specialized instruction. In all other respects, their flight-school experience was identical. The flying skills of all 60 trainees were assessed by Israeli Air Force flight instructors at the end of the second phase of flight training. It was found that the time-sharing skills and strategies developed with the game increased by 30% the probability that trainees would complete flight school. Performance on the game itself was able to predict success in flight school.

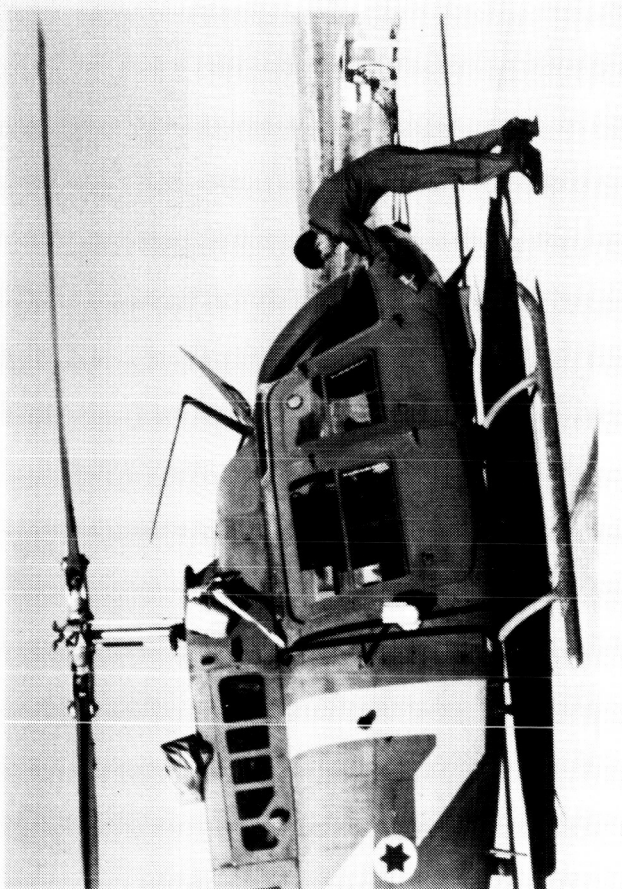
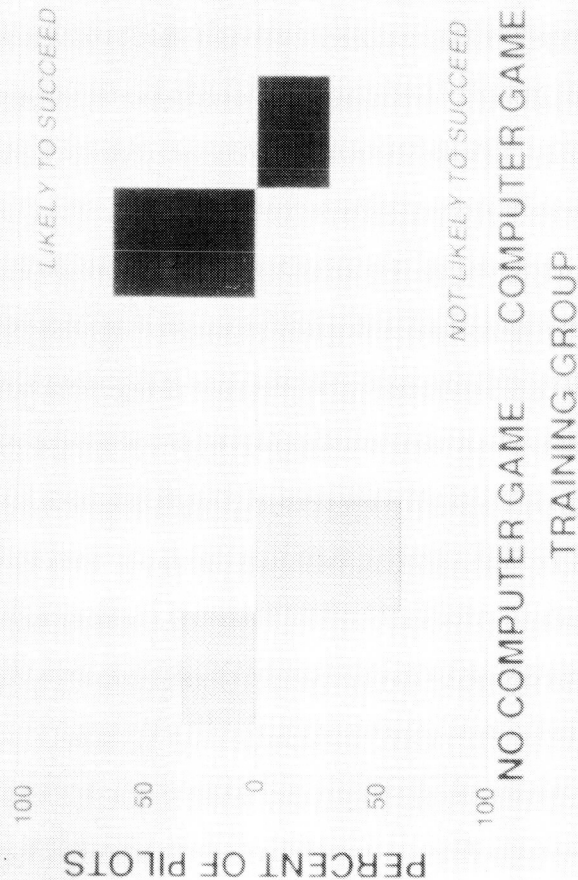
In FY89, final flight school scores will be compared for the three training groups and the feasibility of using computer "game" trainers will be addressed in a final report. Data from the flight school study will be used to develop an improved version of the game. A formal skill-oriented task analysis procedure will be developed to facilitate designing computer-game trainers appropriate for other applications.

Although low-cost computer games have been proposed as training tools for years, this is the first operational test of the concept. The preliminary results are extremely encouraging.

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IMPROVED FLIGHT TRAINING PROCEDURES

IMPACT OF COMPUTER GAME TRAINING ON
 $p(\text{SUCCESS IN FLIGHT SCHOOL})$



Information Management and Transfer

The effective management and transfer of information within the NAS is critical to a safe and efficient air transportation system. Future NAS operations will require flight deck information management systems designed for optimal transfer of airborne, ground and satellite information to aircrews. Information management principles are required that define the information needed, when, and in what form it should be provided.

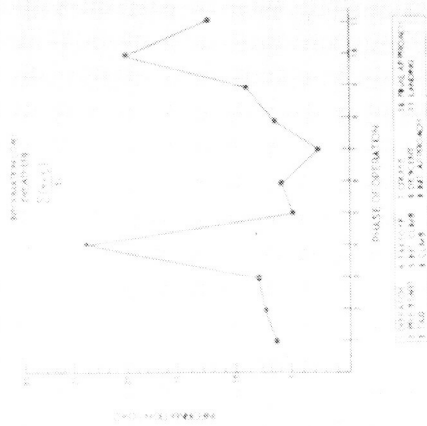
Ames Research Center has an ongoing research program to develop and verify design principles for, and demonstrate the viability of, advanced information management systems for future air transport operations. The program goals are to develop design principles for advanced flight deck information management systems and to develop computer-aided design technology to facilitate the integration of new information technology. As air-to-ground, as well as airborne, information transfer is a part of this research; aircraft-ATC integration in the future NAS will benefit from this effort. In order to attain the program goals by FY92 a multi-faceted approach has been undertaken. This approach includes the development of methodology for quantifying aircrew information requirements and information processing capacity during all flight phases, the identification of current operational problems that could be eliminated by improved system design, the development and evaluation of prototypical information management systems, the development of part system simulation technology as a low-cost design and evaluation tool, and the development of computer-aided design technology based upon information management principles.

During FY88 a number of efforts were successfully completed in support of the program objectives. A test instrument for quantifying aircrew information requirements and methods for deriving information load was developed. Analyses of ASRS incidents of air-ground information transfer incidents were completed. In support of advanced communication management system development, linguistic analyses of communication problems resulting in accidents were completed, as was an aircrew survey of automation requirements of proposed data link communications, and the initiation of an MIT grant to develop an optimal automated clearance delivery system for advanced aircraft. With specific regard to weather information management, a study to determine minimal information transfer requirements for ground-based terminal radar was completed, as was an analyses of ASRS weather-related incidents.

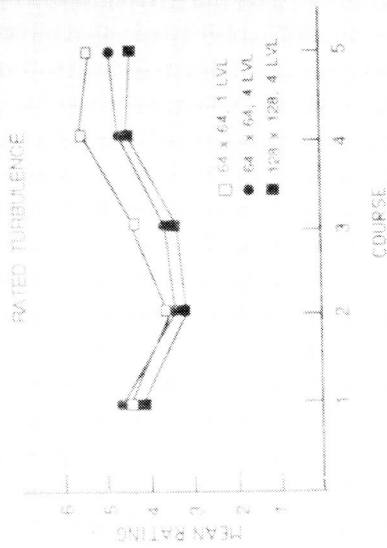
Future efforts planned in support of this program are the development and evaluation of alternative measures of aircrew information load and the development of part systems simulation technology for use in computer-aided information system design. With regard to air-ground communication management, the development of an error-resistant data link communications protocol is planned as is the development of optimal interfaces for display-based communications systems. In weather information management, guidelines will be developed for flight deck integration of ground-based weather information such as low-level windshear and other severe weather avoidance information and continued analyses of weather-related ASRS incidents.

TECHNICAL CONTACT: Alfred T. Lee, ARC (415) 694-6908

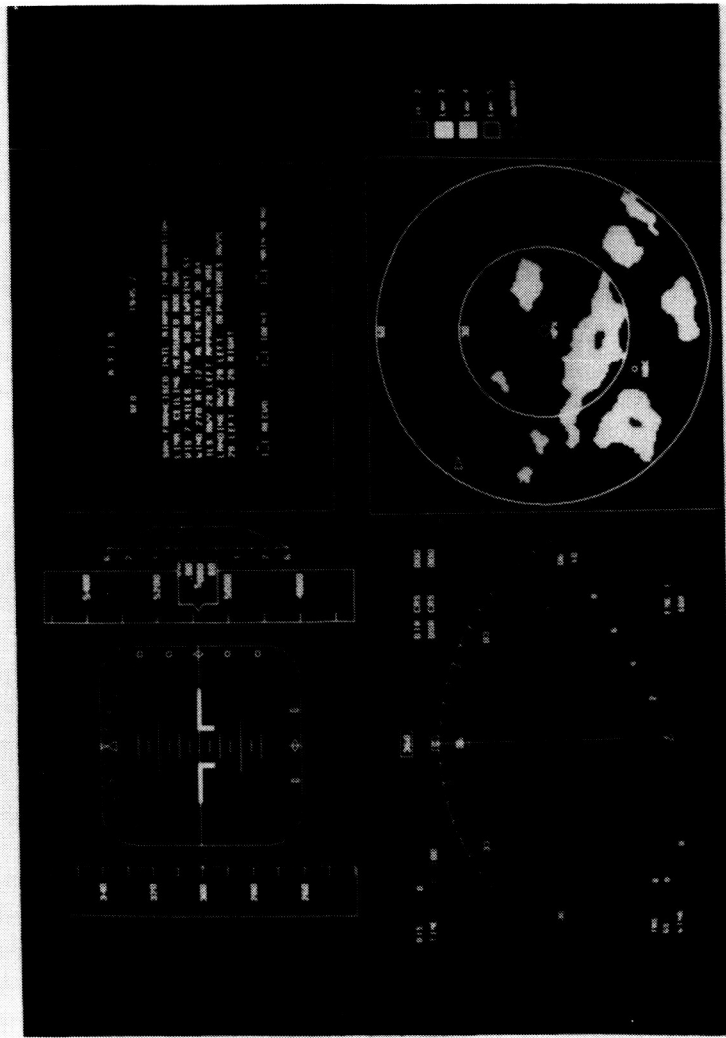
INFORMATION MANAGEMENT STUDIES



Test instrument and metrics for determining aircrew information load



Information transfer requirements for the display of ground-based radar



Part systems simulation for computer-aided information systems design

Evaluation Phase of the Knowledge-Aided Display Design (KADD)

The primary objective is to provide a computer-based display design system that enhances the design process and products by providing on-line assistance through an expert system with knowledge in human factors, ergonomics, and display formats. The objective of the evaluation phase was to compare KADD to other graphics tools widely used by industry for display design.

The evaluation plan consisted of two parts. Part I evaluated the utility of KADD by comparing human "time-to-design" performance for KADD with two other graphic packages. Part II solicited qualitative assessments of KADD from experienced crew system designers by having them use the system. Part I utilized only the display editor portion of KADD with no on-line assistance provided by the expert system. KADD was compared to two PC-based graphic editors: PC PAINTBRUSH and IN-A-VISION. Part II allowed the participants to use the full capabilities of KADD.

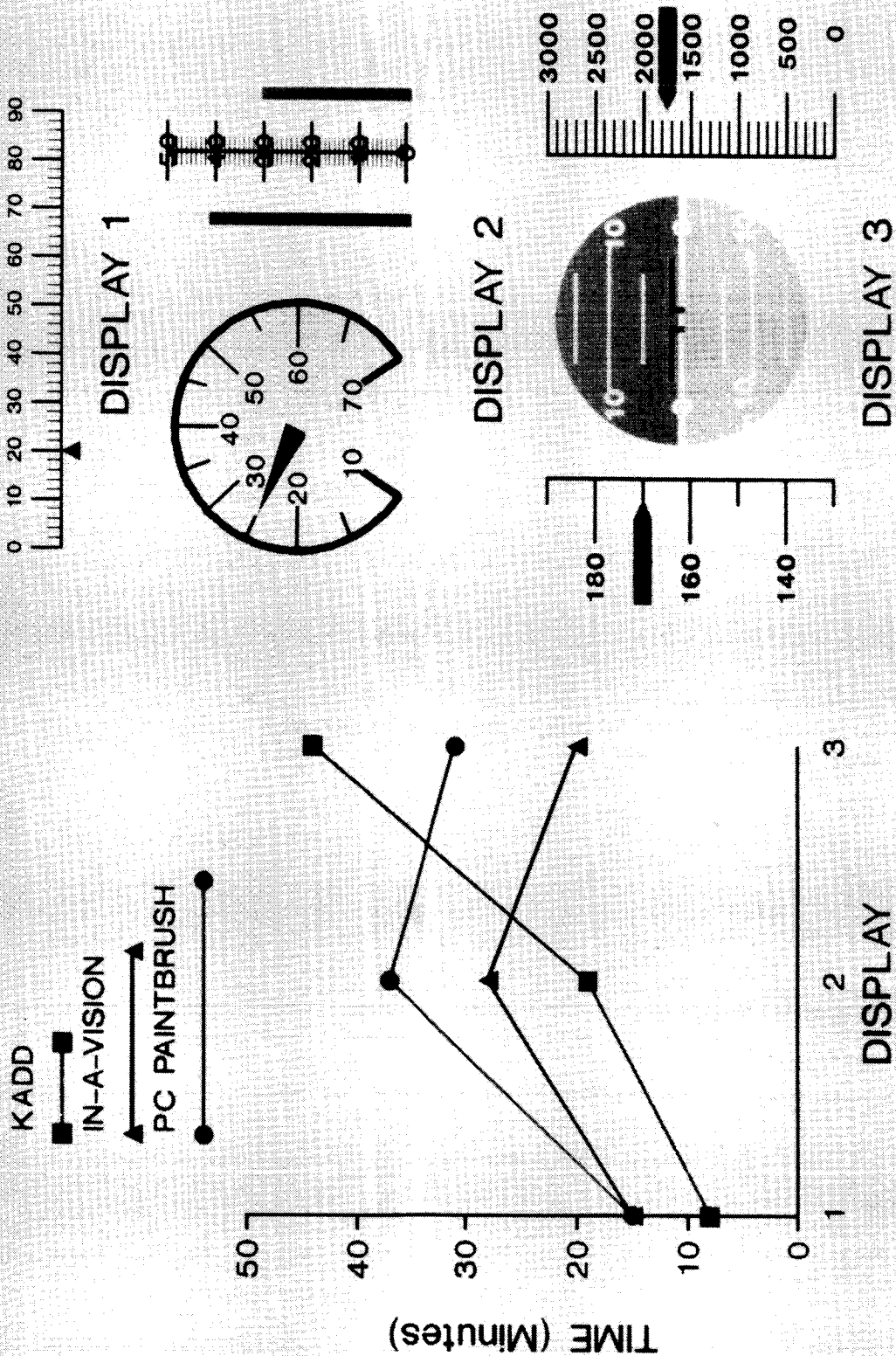
The results of Part I of the evaluation plan are illustrated in the attached figure. The data were averaged across subjects and tasks (create or modify) and show that KADD excels when the display uses predefined graphic elements but suffers when the display design requires manipulations of graphical primitives as "Display 3" did. Although the time-to-design with KADD was greater for "Display 3," the time-to-modify "Display 3" was substantially less, indicating that an initial investment of time will pay off in the long run. In Part II of the evaluation, the subjective responses to KADD were highly positive, although the designers felt the depth of the knowledge base was too shallow. Additionally, the designers wanted the ability to easily define three-dimensional displays, some sort of simulation capability, and the ability to evaluate displays across display elements and formats.

The positive response to KADD indicates a viable concept capable of filling a display designer's needs once integrated with other design tools. Potential benefits are: 1) ergonomically-sound crew stations; 2) reduced display development costs; 3) improved display integration; 4) reduced crew workload; and 5) improved man/machine performance.

The knowledge base on display design will be expanded. Deficiencies in the graphics editor, discovered during the evaluation, will be corrected and a limited animation capability will be added to KADD. The final version of the KADD software will be made available to the public through COSMIC.

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Terence S. Abbott, LaRC (804) 864-2009

DISPLAY "TIME-TO-DESIGN" COMPARISON



Workload and Performance Prediction

The pilot's ability to use and integrate cockpit displays, controls, and computer aids effectively has been recognized as the key to overall system effectiveness. Pilot workload has been identified as a critical factor in evaluating cockpit designs or assessing the feasibility of mission requirements. To guide designers, questions about workload must be answered early in design. Therefore, military and civilian users and industrial designers of advanced rotorcraft require accurate predictions of workload long before workload and performance can be measured directly.

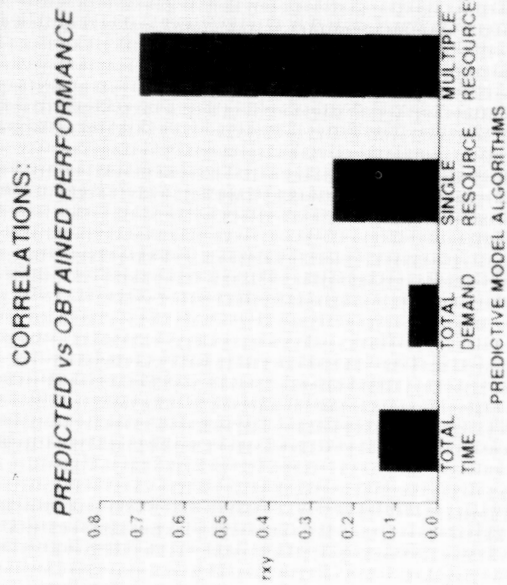
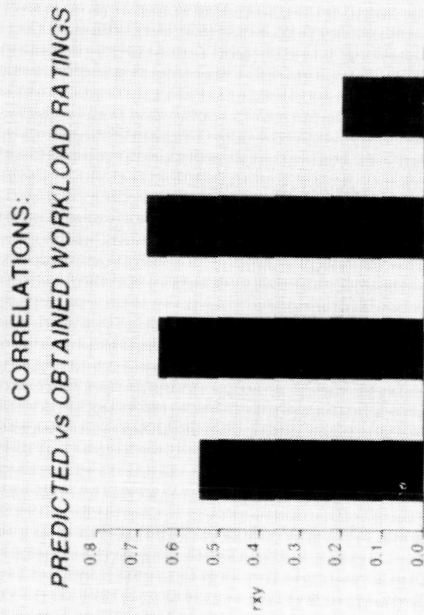
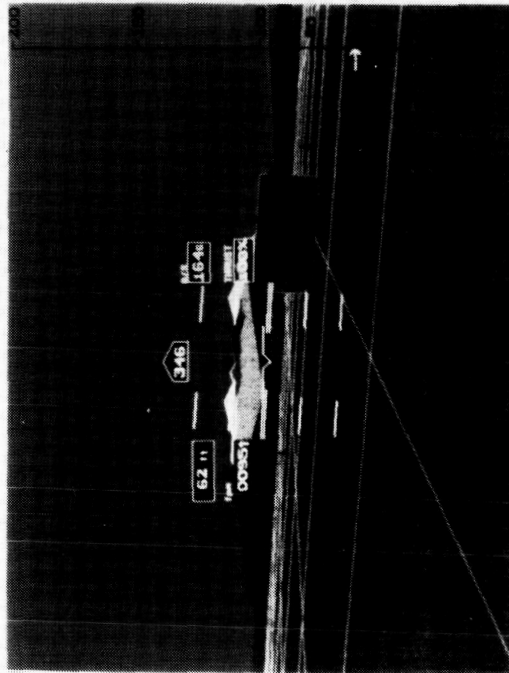
Most predictive models are based on time-line analyses of the sequences of tasks using estimates of completion times and demand levels. However, task completion times provide little information about effort associated with performance and are difficult to validate. Pilots rarely perform flight tasks in the exact sequence and for the same durations assumed by the model. Also, pilot workload reflects skill level, strategies adopted, and effort exerted rather than task demands directly. The sequence and structure of task components have a large effect on workload but are ignored by many models. It is particularly difficult to predict the impact on workload of design concepts for systems that have not yet been built. And, measures of workload and performance are often uncorrelated.

Researchers at NASA Ames and the University of Illinois are addressing these problems. Task and skill analysis procedures have been developed to decompose flight tasks into components for analysis. The relationships among pilot workload and performance and variations in display design and modality, control design and modality, information processing demands, task schedules, and various types of difficulty manipulations have been examined. A database of nominal workload values for activities performed in helicopter missions has been developed. Simulation research has been performed at Ames to determine whether subtask workload levels are stable in the presence of different competing task demands.

The key is selecting the most appropriate algorithm to combine information about task components to predict the workload of complex tasks. Ames, at the University of Illinois, compared algorithms used by current workload prediction models in a helicopter simulation. The Total Time model is based on the number of tasks performed per unit time. The Total Demand model sums the individual demands of tasks performed per unit time. The Undifferentiated Capacity model sums individual task demands with an additional cost for time-sharing. The Multiple Resources model bases its predictions on the degree to which concurrent tasks compete for limited input, output, and processing resources. As competition increases, it is assumed that workload will increase and performance will degrade. An interesting dichotomy was found between the models' abilities to predict. Models that integrate task demands over time predicted subjective workload ($r=0.65$) but not performance ($r=0.11$), whereas the model based on competition for resources predicted performance ($r=0.47$) but not subjective workload ($r=0.10$). The data illustrate that workload and performance are not the same suggesting that users should be cautious selecting models and interpreting output. Information from these and previous studies will be integrated into the predictive model under development at Ames resulting in a publicly available computer model that can be used to predict workload and performance early in design.

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COMPARISON OF ALGORITHMS USED TO PREDICT WORKLOAD AND PERFORMANCE



RC89-203(3)

ROTORCRAFT HUMAN FACTORS

Human Factors Issues in Civil Medevac Operations

Although hospital-based Emergency Medical Service (EMS) helicopters play a critical life-saving role, they have the worst safety record of any segment of aviation. Since 1980 the EMS industry has averaged 12.3 accidents per 100,000 flight hours. The NTSB cited weather-related factors as the most significant influence in a recent survey. These, coupled with program competition, demands by medical personnel, crew schedules, and pilots' "can-do" attitudes may produce an environment that precipitates errors and poor pilot judgment.

The high civil EMS accident rate demands an immediate solution, however, imposing new regulations without the benefit of adequate research will not solve the problem. Thus, NASA researchers have initiated several activities in this area, capitalizing on their expertise in gathering and analyzing aviation incident data and knowledge about pilot error, workload, fatigue, circadian desynchronization, and other potentially relevant areas. In addition, the possibility of establishing an expanded program in cooperation with the FAA is being explored.

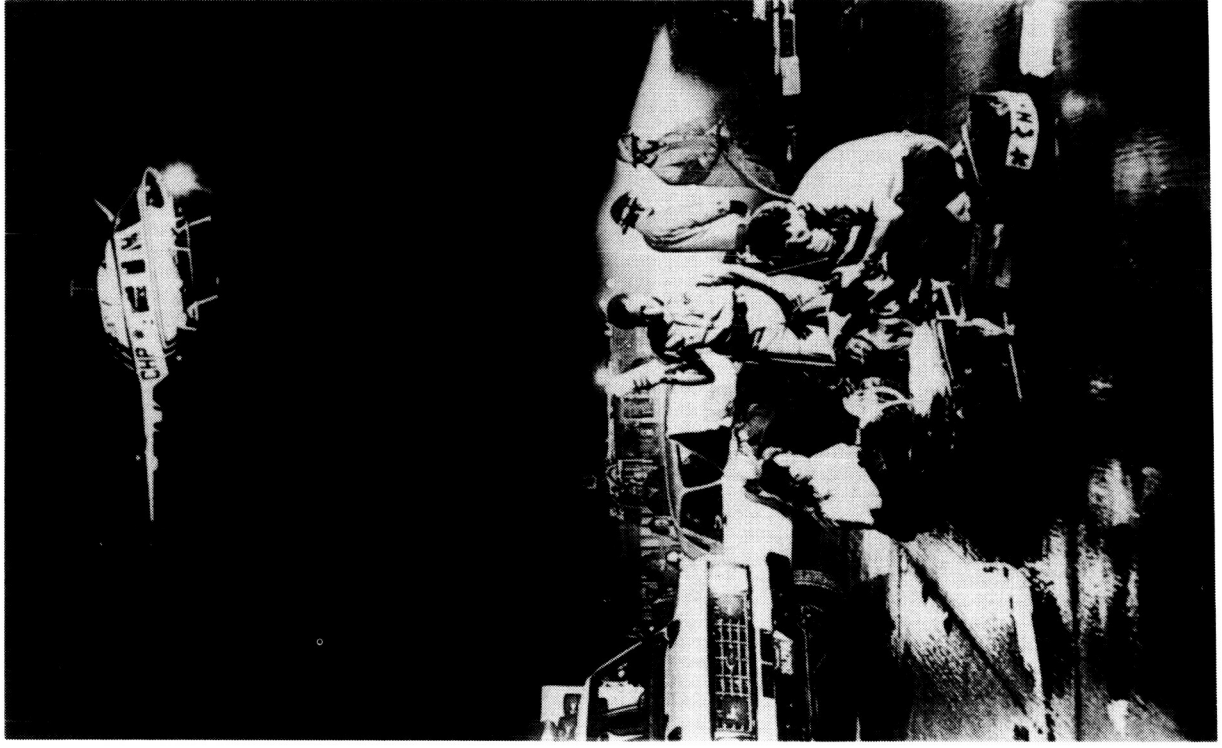
Two government/industry workshops were held, providing an opportunity for representatives from many organizations responsible for medical evacuation to share common experiences, problems, and solutions. The EMS Safety Network was established within the framework of the Aviation Reporting System (ASRS) with the support of the Helicopter Association International, National EMS Pilots Association, Airborne Law Enforcement Association, NTSB and the FAA, among others. The goal of the system is to develop a comprehensive data base of civil, public service, and military medevac incidents, which can be analyzed to assess the effects of crew size, duty hours, procedures, missions, etc., on pilot workload, fatigue, judgment, and performance, and to compare the consequences of different approaches to medical evacuation. Information from the EMS Safety Network in conjunction with inflight assessments of public service and hospital-based medevac crews will focus subsequent research efforts on the most critical areas. An inflight evaluation of helicopter law-enforcement crews was performed to evaluate the utility of research methods proposed for use in EMS helicopters. Subjective and physiological measures of crew workload were obtained and a detailed analysis of crew communications and activities was completed. Subjective ratings and the content of crew communications indexed crew workload. Verbal fluency for cockpit communications indexed fatigue. An inflight evaluation of EMS flight crews has been initiated and will be completed in 1989. This experiment will investigate: 1) pilot workload; 2) pilot decision-making; 3) cues used to maintain geographical orientation; and 4) communications.

Many EMS incidents and accidents have been attributed to poor pilot judgment. Pilots accept or continue flights under deteriorating weather conditions or when other risk factors are present. To improve pilots' abilities to evaluate relevant factors and to make more appropriate decisions, a pre-flight risk assessment procedure (SAFE), adapted from U.S. Army and Coast Guard systems, was developed. It will be tested in an operational setting and refined, as needed. The final system will be publicly available.

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HUMAN FACTORS ISSUES IN CIVIL MEDEVAC OPERATIONS

- SPONSORED TWO GOVERNMENT, INDUSTRY WORKSHOPS
- INITIATED ASRS/EMS SAFETY NETWORK
- COMPLETED TWO INFLIGHT EXPERIMENTS
- DEVELOPED PRE-FLIGHT RISK-ASSESSMENT PROCEDURE FOR EMS PILOTS
- INITIATED OPERATIONAL TEST OF RISK-ASSESSMENT PROCEDURE



Identification of Wind Shear Hazard Index

The key to the development of airborne wind shear detection, warning, and avoidance systems is the identification of a hazard index, which exhibits functional dependence on atmospheric states that can be reliably sensed and scales with available aircraft performance in such a way that the index predicts impending flight path deterioration. This hazard index must also account for factors such as: statistical nature of the wind shear threat; fusion of present position and "forward looking" sensor capabilities; and the development of objective methods for determining systems warning thresholds, which consider the potential for nuisance alerts. The objective of this research was to derive an aircraft-specific hazard index based on accepted fundamentals of flight mechanics and current state of knowledge of wind shear phenomena.

An analysis was conducted that revealed the importance of aircraft energy balance for flight in spatially and temporally varying windfields. This energy state analysis showed that aircraft motions should be referenced to the accelerated and non-homogeneous air mass that typifies wind shear phenomena. Aircraft climb polars were generated that exemplify wind shear impact on performance and parameter sensitivity analyses were conducted.

The analysis revealed that the rate of change of specific energy (potential climb rate) depends linearly on a non-dimensional parameter, which only contains information regarding air mass movement. Further analysis indicated that the subject parameter can be physically interpreted as the loss in available excess thrust-to-weight ratio due to downdrafts and horizontal wind shear, thus providing an aircraft-specific index on which to base warnings. This hazard index, referred to as the F-Factor, is defined in the attached figure, and its application to a warning system concept is also shown. A preset hazard threshold, F_o , is incorporated which, when exceeded below a specified altitude, provides an alert to the crew. Any combination of horizontal shear and/or vertical wind that falls within the diamond region indicates safe aircraft operation in relation to available excess thrust to weight ratio.

The accomplished research has yielded new concepts for airborne wind shear warning and alerting systems. The significance and impact of the derived techniques have been acknowledged by domestic aircraft and avionics manufacturers and by international companies such as Aerospatiale.

Future plans include conducting full system piloted simulation evaluations using NASA-developed wind shear models and completing ongoing analysis to minimize nuisance warning probability.

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HAZARD INDEX

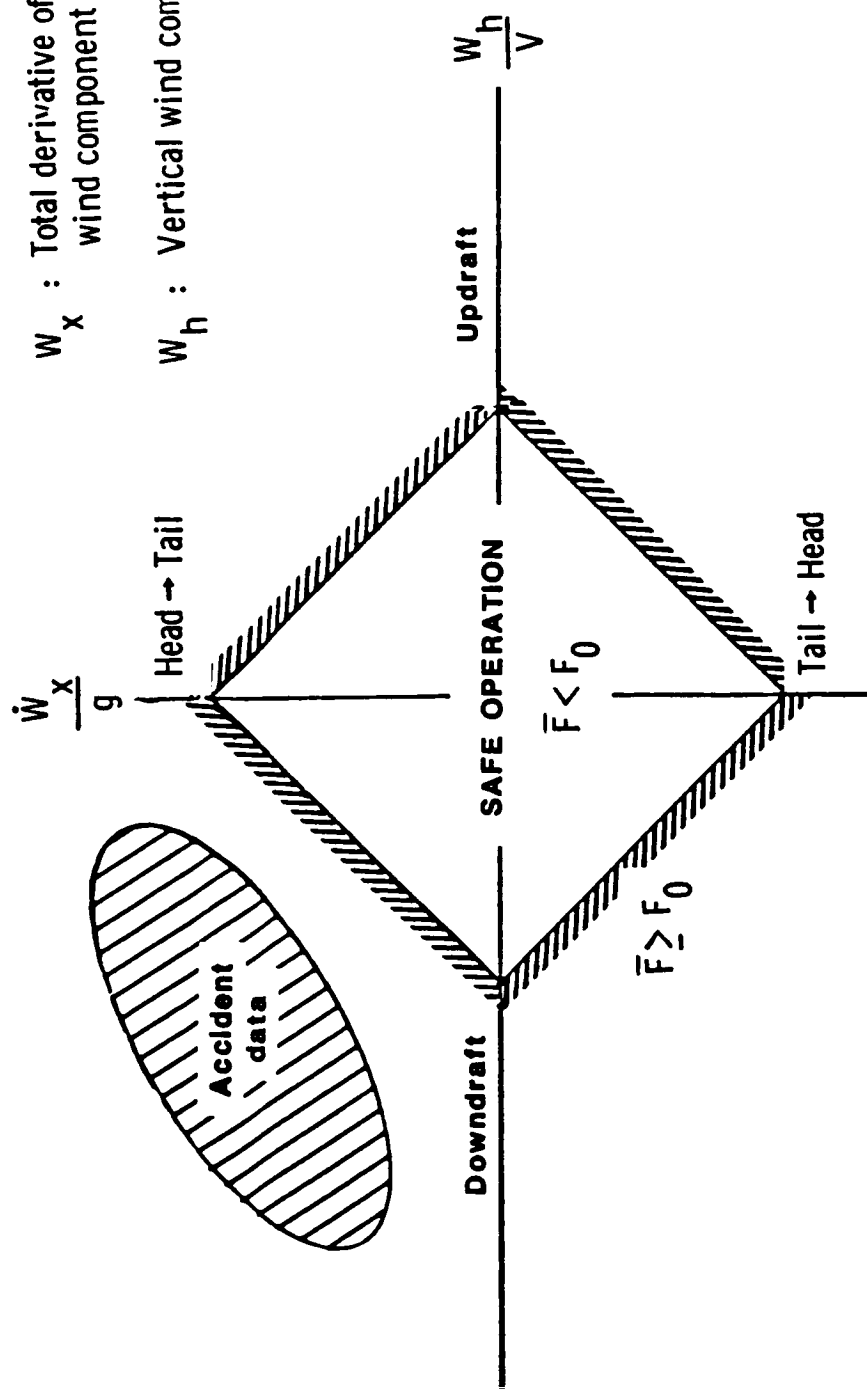
CAST

$$\bar{F} = \frac{|\dot{W}_x|}{g} + \frac{|W_h|}{V} \geq F_0$$

V : Aircraft airspeed

W_x : Total derivative of horizontal wind component

W_h : Vertical wind component



Computational Models of Attention and Cognition

Human operators are severely limited in their ability to process and respond to multiple information sources. Aviation and space environments impose severe visual, auditory, and decision-making demands in situations where human failure can have catastrophic results. Information overload has been identified as a major contributor to error in military aviation, especially helicopter NOE operations, and in critical monitoring tasks such as air traffic control and ground control of space missions.

The ultimate solution to problems arising from limitations on attention and cognitive capacities will come from optimal allocation of function between human and machine combined with optimal configuration of multi-modal displays and controls. The realization of such optimization depends on a deeper understanding of attentional control. This can be achieved by developing validated computational models of human information processing.








The Ames Research Center has an ongoing research program in attention and human cognition focussed on determining the mental resources underlying complex task performance. This research has identified stimuli that control attention and situations where distraction will be unavoidable, making it possible to design displays that better capture and direct an operator's attention. Work on cognitive architecture has led to models of simple multi-task settings that will aid decisions about the use of speech controls and displays, and the allocation of tasks between the human operator and automated subsystems. Current research will extend these findings to more complex task environments by: 1) developing methods for mapping complex tasks onto underlying mental resources; 2) conceptualizing, implementing and iteratively refining computational models of human cognition; and 3) developing quantitative models of the allocation, control, and mechanisms of human attention.

Several aerospace scenarios are being investigated as a basis for analysis and model development. These include: 1) ground control of manned and unmanned space operations; 2) helicopter Nap-of-the-Earth and Search-and-Rescue operations; and, 3) Air Traffic Control and anticipated Space Station Proximity Control operations.

The research program involves extensive in-house research and model development while supporting related modeling efforts at universities. Related efforts at Ames address workload, methods of assuring proper levels of alertness in civil air transport, and pilot error.

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FORMAT OF EXPERT SYSTEM: RECOMMENDATIONS AND EXPLANATION



Inquiry about ESI's
New Flight Plan

ESI recommends that the crew maintain 250 for approximately 50 minutes beyond where the current flight plan says to climb to 290. This recommendations is made for the following reasons :

Strength of Turbulence

Length of Turbulence

Current Altitude

Expert System Interface Project (ESI)

The Expert System Interface project is designed to address issues concerning the introduction of intelligent planning systems into the cockpit. These issues include:

1. What role should the system play?
2. How should the crew and the system communicate with each other?
3. What types of explanation capabilities are needed?
4. How should these systems be evaluated?

These research questions are being studied in the context of an enroute flight path planning system.

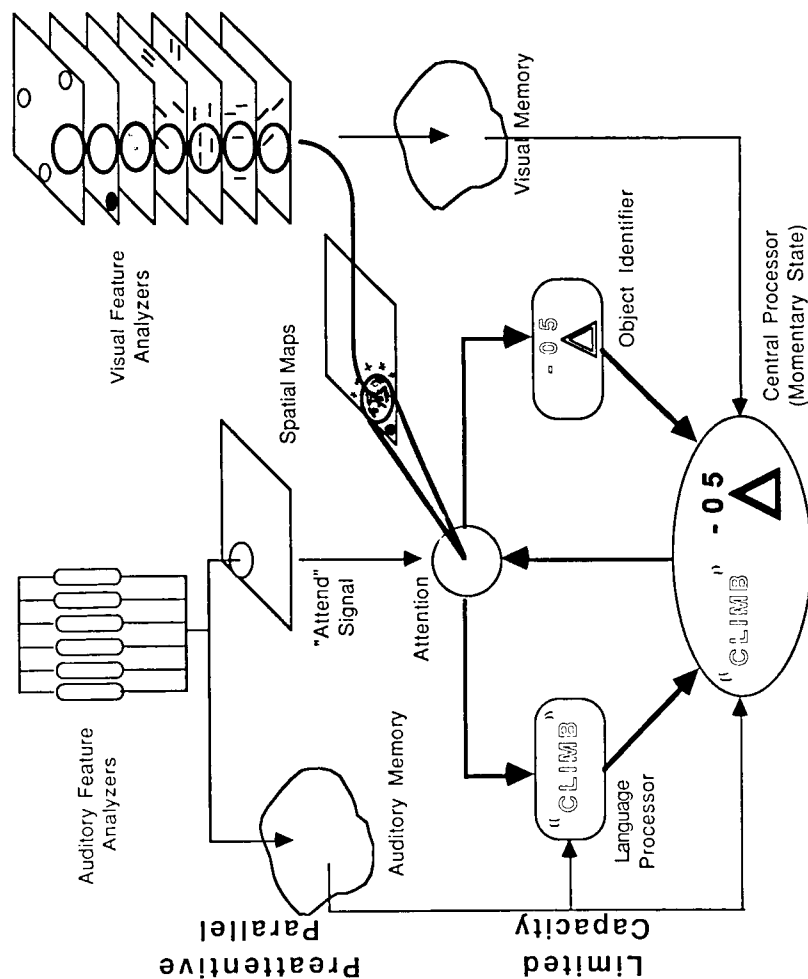
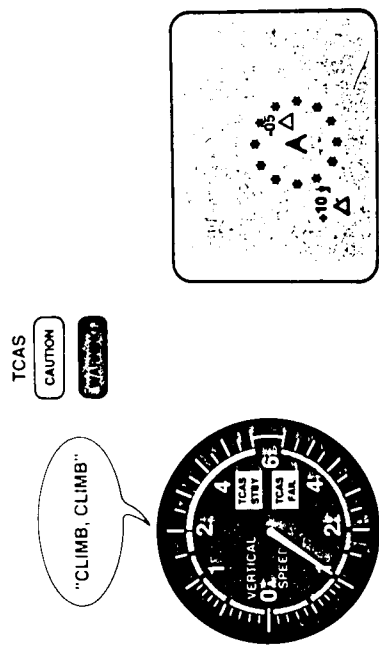
Pilots seem more willing to accept knowledge-based systems that act as cooperative decision aids rather than autonomous decision-makers. For a cooperative system, the human interface is a critical component, linking the pilot to the underlying system. The design of this interface is a major constraint on the design of the underlying system.

We are currently developing a methodology to aid in the design of these cooperative systems. The research issues mentioned above will help us formulate guidelines for developing interfaces to cooperative decision aids. For example, is the appropriate role of the system that of a consultant, critic, what-if system, or a combination of these? How does the role affect what errors the crew will make? Does the crew need access to raw data or do they prefer the system to aggregate and transform the data to fit the current context?

This project was originally a NASA Graduate Student Research Grant. The first year of that grant demonstrated the importance of four issues in developing cooperative decision aids. These are: 1) the role of the system; 2) its explanation capabilities; 3) the specific information displayed/conveyed to the crew; and 4) the large degree of individual differences. During this second year, the project has been expanded to include an in-house NASA project, a university consortium agreement with Ohio State University, and a Small Business Innovative Research (SBIR) grant with Decision Sciences Corporation. These groups are currently working together to develop and evaluate interfaces to a cooperative enroute flight path planning system.

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FUNCTIONAL BLOCK DIAGRAM OF COMPUTATIONAL VISION/AURAL SYSTEM AT AMES RESEARCH CENTER



Human Factors - Space

The objectives of the Space Human Factors Research and Technology Program are to provide a technology base for intelligent operator interfaces, especially with autonomous subsystems, and to develop a new generation of high performance space suits, gloves, and tools/end effectors to meet the requirements of advanced space missions. The technology base is intended to provide increased productivity, efficiency, and safety in complex manned operations within automated onboard systems and extravehicular activities (EVA) environments.

Crew station research is the first of two major areas. Development of methods for the astronaut to supervise, monitor and evaluate the performance of robotic systems, other space subsystems, and orbital vehicles are key areas of research. Fundamental understanding of the human visual and information integration capabilities provides a technical basis to develop mathematical, anthropometric, and graphical models of human interactions with space systems and equipment. The capability to perceive, evaluate and control robotic assistants, computer-generated images of actual systems and space structures, and to interact with such assistants, systems and structures, via computer models, has achieved an initial feasibility under the name virtual workstation research. A large-scale mock-up of the viewing cupola of the Space Station provides the means to study the effects of a 90-minute cycle of light-darkness on windows, on displays, and on the astronaut's tasks in the cupola for proximity operations.

The second major area is development of a new extravehicular activity (EVA) space suit and gloves. A major milestone was accomplished with the completion of the AX-5 hard suit and its initial test for mobility and ease of donning and doffing. This suit is a prime candidate for use in the Space Station and allows the astronaut to don the space suit without extensive pre-breathing of oxygen. It is being tested and evaluated against a second new EVA suit, ZPS Mk. 3, which has both hard metal and fabric features. Also under research and technology development is a project to study and develop end effector mechanisms whereby the EVA-suited astronaut can control and supervise robotic assistants. An important feature of this is a force feedback capability whereby the user receives feedback of the proportional amount of force being applied by the robotic end effector to the object being grasped. Also, the human factors research program includes development of new methods to display information on the space suit's visor to give to the astronaut a capability to interact with displayed information by means of voice commands.

Emphasis in the Space Human Factors Research Program is placed on technology baseline studies and development of methods, techniques, and data to support productive and safe operations by the astronaut and crew as they interface with complex systems, advanced automation, and robotic assistants.

PROGRAM MANAGER: Dr. James P. Jenkins
NASA/OAST/RC
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Networks for Image Acquisition, Processing, and Display

The human visual system comprises layers of networks that sample, process, and code images. Understanding these networks is a valuable means of understanding human vision and of designing autonomous vision systems based on network processing. Ames Research Center has an ongoing program to develop computational models of such networks.

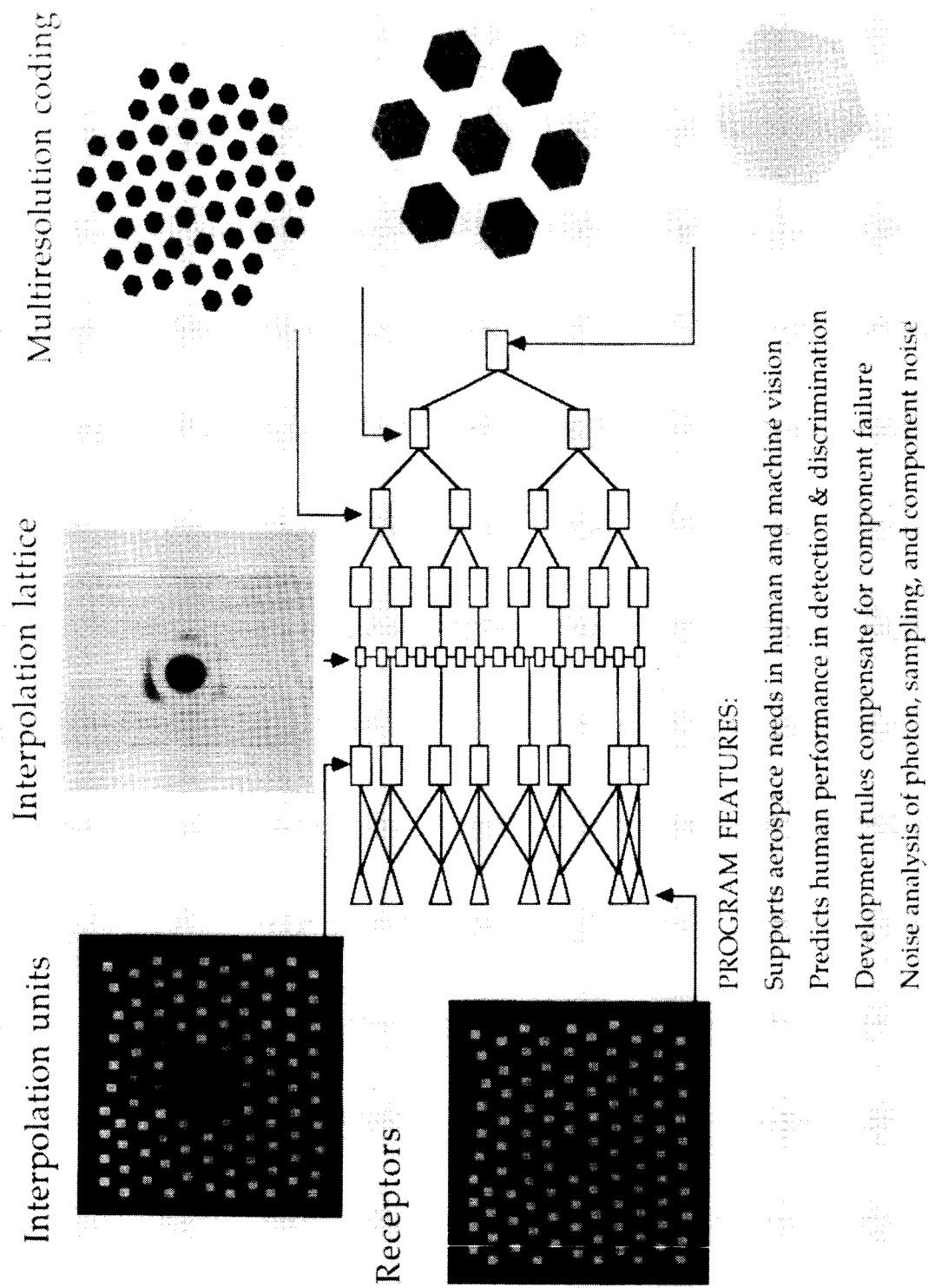
The models predict human performance in detection of targets and in discrimination of displayed information. In addition, the models are artificial vision systems sharing properties with biological vision that has been tuned by evolution for high performance. Properties include variable density sampling, noise immunity, multi-resolution coding, and fault-tolerance. The research stresses analysis of noise in visual networks, including sampling, photon, and processing unit noises.

Specific accomplishments include: 1) models of sampling array growth with variable density and irregularity comparable to that of the retinal cone mosaic; 2) noise models of networks with signal-dependent and independent noise; 3) models of network connection development for preserving spatial registration and interpolation; 4) multi-resolution encoding models based on hexagonal arrays (HOP transform); and 5) mathematical procedures for simplifying analysis of large networks.

This program has resulted in six papers published or in press during the last year. Parts of this work were done in collaboration with Stanford University.

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Andrew Watson, ARC (415) 694-6257

NETWORKS FOR IMAGE ACQUISITION, PRE-PROCESSING, & CODING



Pyramid Image Codes

All vision systems, both human and machine, transform the spatial image into a coded representation. Particular codes may be optimized for efficiency or to extract useful image features. We have explored image codes based on the primary visual cortex in man and other primates. Understanding these codes will advance the art of image coding, autonomous vision, and computational human factors.

In the cortex, imagery is coded by features that vary in size, orientation, and position. We have devised a mathematical model of this transformation called the Hexagonal-oriented Orthogonal quadrature Pyramid (HOP). In a pyramid code features are segregated by size into layers with fewer features in the layers devoted to large features. Pyramid schemes provide scale invariance, and are useful for coarse-to-fine searching and for progressive transmission of images.

The HOP Pyramid is novel in three respects: 1) it uses a hexagonal pixel lattice; 2) it uses oriented features; and 3) it accurately models most of the prominent aspects of primary visual cortex. The transform uses seven basic features (kernels), which may be regarded as three oriented edges, three oriented bars, and one non-oriented "blob." Application of these kernels to non-overlapping seven-pixel neighborhoods yields six oriented high-pass pyramid layers, and one low-pass (blob) layer. Subsequent high-pass layers are produced by recursive application of the seven kernels to each low-pass layer.

Preliminary results on use of the HOP transform for image compression show that 24-bit color images can be codes at about 1 bit/pixel with reasonable fidelity. Future work will explore related codes and more detailed comparisons to biological coding, and applications to motion processing and shape perception.

TECHNICAL CONTACT: Andrew B. Watson, ARC (415) 694-5419

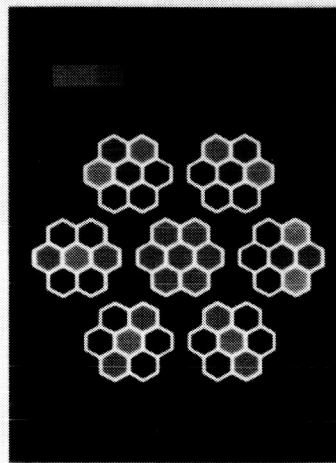
PYRAMID IMAGE CODES

IMAGE CODES REQUIRED FOR

- AUTONOMOUS VISION
- IMAGE STORAGE & TRANSMISSION
- MODELING HUMAN VISION

HEXAGONAL ORTHOGONAL ORIENTED PYRAMID (HOP)

- EASY TO COMPUTE AND INVERT
- HIGHLY EFFICIENT
- MATCH HUMAN VISION
- ORIENTED KERNELS
- HEXAGONAL LATTICE



ORIENTED, ORTHOGONAL KERNELS

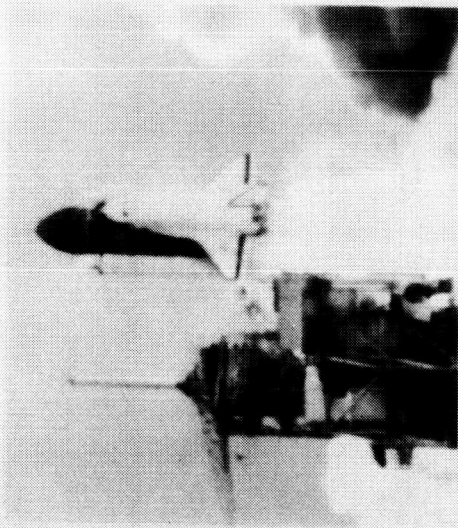
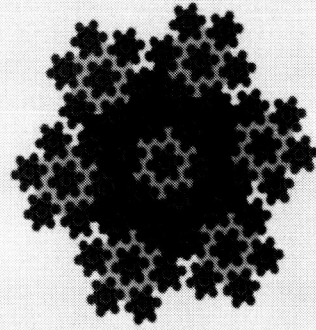


IMAGE CODED AT 1 BIT/PIXEL



PYRAMID OF KERNELS

Auditory Display Systems Research

Auditory cues can provide a critical channel of information in complex spatial environments during periods of high visual workload and when visual cues are limited, degraded, or absent. Some or all of these conditions will be present in Space Station operations such as the monitoring and control of autonomous and semi-autonomous telerobots, the conduct of extravehicular activity (EVA) and use of visor displays, and management of complex onboard Space Station systems. Auditory information can also enhance the utility of virtual environment displays such as NASA's Virtual Workstation.

Spatial auditory displays require the ability to generate localized sound cues in a flexible and dynamic manner. NASA Ames is currently investigating the underlying perceptual principals of auditory displays and is also developing a prototype signal processor based on these principles. Rather than use a spherical array of speakers, the prototype will maximize portability by synthetically generating three-dimensional sound cues in realtime for delivery through earphones. Unlike conventional stereo, sources will be perceived outside the head at discrete distances and directions from the listener. This is made possible by numerically modeling the effects of the outer ears (the pinnae) on the sounds perceived at various spatial locations. These "pinnae transform filters" can then be applied to arbitrary sounds (voices, for example) in order to cause them to seem spatially located.

A non-directional audio display, based on well-established electronic sound synthesis standards, is also under development. An initial version of an auditory symbol editor will be completed by the end of the year. This system will enable researchers to investigate auditory symbology for communication of meaning apart from verbal content. In addition, experience in the integration of this system with the Virtual Workstation will benefit the later incorporation of the spatial audio display system.

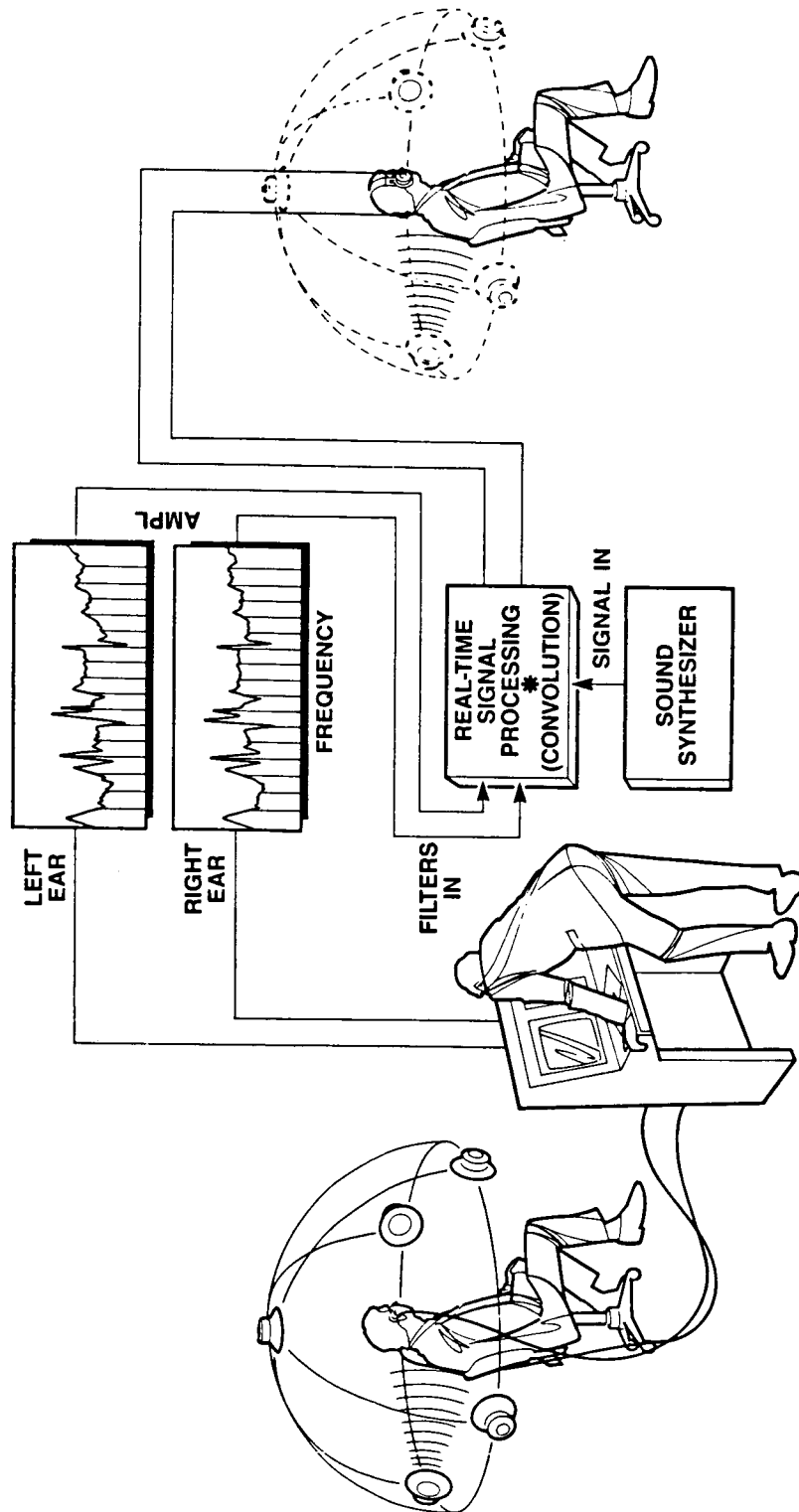
Cooperative research with Dr. Frederic Wightman of the University of Wisconsin, Madison, is under way. This research includes perceptual validation of the synthesis technique in both practical and more basic areas. Practical issues include required computational resolution and signal bandwidth. Basic issues include acoustic determinants of individual differences in localization behavior. This year, a realtime signal processor, the "convolvotron", has been designed and a prototype is currently being fabricated. An initial version capable of synthesizing a single localized source will be available by the end of FY88.

Plans include adaptation of Dr. Wightman's measurements of the pinnae transform filters for use in the convolvotron; evaluation of the perceptual validity of the convolvotron-generated directional audio; and the implementation of the processor as a printed circuit board for greater reliability and ease of replication. A convolvotron capable of presenting three independent and simultaneous directional sound sources is scheduled to be completed in FY89. The convolvotron will be incorporated into the Ames Virtual Workstation and will undergo system calibration and performance evaluation in specific applications.

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3-D AUDITORY DISPLAY: SYNTHESIS TECHNIQUE

OAS-T



**SYNTHESIZED
CUES**

**PINNAE TRANSFORMS
DIGITIZED**

**PINNAE (OUTER EAR)
RESPONSES MEASURED
WITH PROBE MICROPHONES**

Integrated Rendezvous and Proximity Operations Displays

The purpose of this research program is to provide and evaluate display concepts for Space Station Proximity Operations displays or other generic displays of relative orbital position. The display concepts will emphasize the use of metrical computer graphics to present spatial information to astronauts or other crew members.

The prototype Prox-Ops perspective display implemented in the Ames Proximity Operations Mockup has been supplanted by a substantially improved version currently implemented on an IRIS workstation. This display uses inverse dynamics to remove control nonlinearities associated with orbital maneuvering and provides a graphical tool for visualizing structural, plume-impingement, and velocity constraints on orbital maneuvering. Two experiments evaluating performance of untrained users have been completed. Very brief training periods are needed to learn to plan orbital maneuvers with this system.

Preliminary experimentation with the improved display has uncovered a new visual illusion associated with 3D interpretation of multi-orbital trajectories. Careful selection of the display's viewing direction may control this problem, but continued research into required geometric, symbolic, and computational enhancements is required to further optimize presentation of 3D orbital information. This continued work will be conducted jointly by NASA Ames, The Israel Institute of Technology (TECHNION), and U.C. Berkeley.

The improved display has been the subject of part of a NASA press release and has been described in several national popular magazines and professional trade journals.

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 Arthur J. Grunwald, TECHNION (415) 694-6147

Helmet Display Development

A helmet-mounted display (HMD) is being developed to increase crew productivity and safety in EVA. An HMD would replace the cardboard cuff checklists and the displays and controls module currently used. However, it will only be useful if it can be used quickly, easily, and effectively without interfering with the task at hand.

The HMD displays and controls must be readily accessible to the user while he or she is working. Therefore, a combination of voice commands and flexible displays is being studied. The displays must be capable of showing everything from numerical values of suit parameters to detailed photographs and schematics of the object being serviced. Candidate formats for the displays have been designed and evaluated by crew trainers, crew members, and EVA engineers. Similarly, the use of a voice command system will leave the astronaut's hands free while the displays are being selected. The emphasis this year has been on developing a vocabulary that is concise, complete, and natural. Tests have been conducted on words to determine separability by commercial voice analyzers. Also, techniques for updating voice templates during the performance of EVA have been studied and evaluated.

Technology development this year has centered on interfacing the prototype HMDs to computers for generating the displays, and on developing tools for easy design and presentation of displays. During the coming year, displays will be evaluated experimentally for clarity and ease of use. The vocabulary will be refined, and the operating system for the HMD display logic will be further developed.

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ADVANCED HELMET DISPLAY FOR EVA SUIT AT JOHNSON SPACE CENTER



Virtual Workstation

The application of human capabilities outside vehicles and shelters will be a vital element of Space Station, Moon base, and Mars exploration missions. While extravehicular activity (EVA) will account for much of the human presence, and automated robots will assist in many chores, telepresence and interactive visualization systems will provide essential complementary capabilities.

To support NASA's mission requirements for augmented human capability, Ames Research Center is continuing to develop the Virtual Workstation. This device is a multi-sensory personal simulator and telepresence device. It consists of a custom built wide field-of-view stereo head-mounted display, a custom video processor, magnetic head tracker, fiber optic gloves, magnetic gesture trackers, voice input/output, and an audio symbology generator. The Virtual Workstation is being developed: 1) to enable greatly improved situation awareness in complex spatial environments; 2) to enable high fidelity telepresence for control of telerobots; 3) to simulate workstations, cockpits, and module interiors; 4) and to enable improved visualization interfaces for exploration of planetary surface data.

This year, the third-generation monochrome viewer and video processor electronics have been completed. Ad hoc demonstration software has been replaced by a system software library for programming the viewer, tracker, and glove, and an improved object database format and its support tools. A directional acoustic signal processor, the "convolutron," has been designed and is being fabricated. Initial Operational Configuration (IOC) of the prototype system will be achieved by the end of the year. Upon reaching IOC, the hardware and software will be integrated into a stable configuration for user interface research, and generic development will end. Currently, a major documentation activity is underway, and technology transfer activities are increasing.

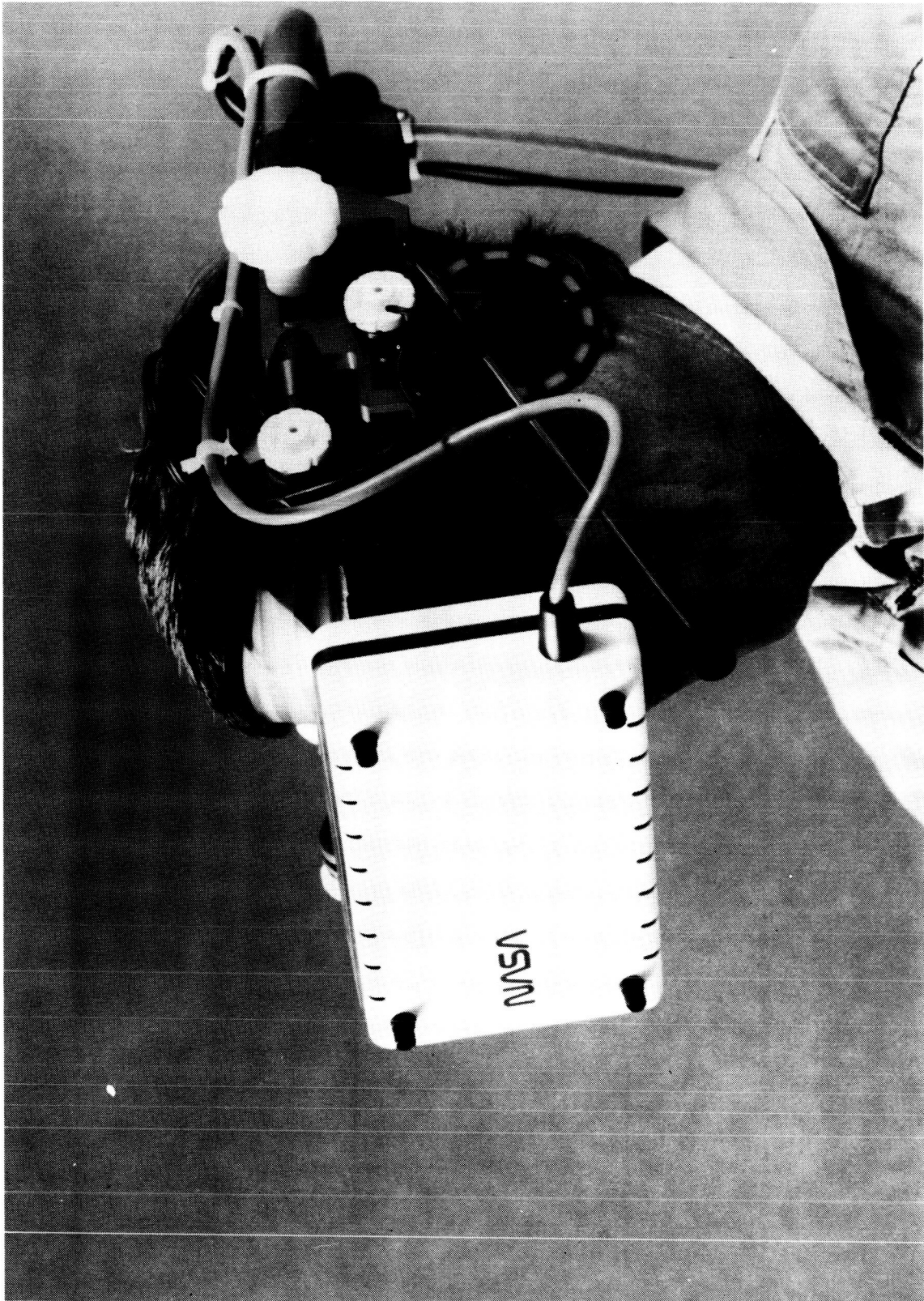
Application software is under development for a joint effort between NASA-Ames and NASA's Jet Propulsion Lab (JPL) in which the Virtual Workstation will be used to provide an alternate operator interface in telerobotics supervisory control. In another project, a highly dextrous anthropomorphic end-effector under development at JPL and the Ames Virtual Workstation will demonstrate high fidelity dextrous telepresence between Ames and JPL within the next 3 years.

As part of the Pathfinder Humans-in-Space Program, user interfaces for virtual exploration of planetary surfaces will be developed. Users will be able to explore the planets as integrated environments, not merely through individual pictures. As a spinoff to aeronautics research, specific plans are being developed to provide systems for use in rotorcraft helmet-mounted-display research and computer-aided cockpit design tools.

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Dr. Beth Wenzel, ARC (415) 694-6290

VIRTUAL WORKSTATION DISPLAY



Advanced EVA Suit Technology

The Ames Research Center has an ongoing program to address EVA suit technology requirements for the Space Station. A product of this effort has been the development of the Ames AX-5 space suit. The overall objectives of this development effort have been to provide a high mobility suit technology that eliminates the need for prebreathing, provides increased hardware and systems life, minimizes maintenance, provides increased hazard protection, and accommodates a large population sizing capability.

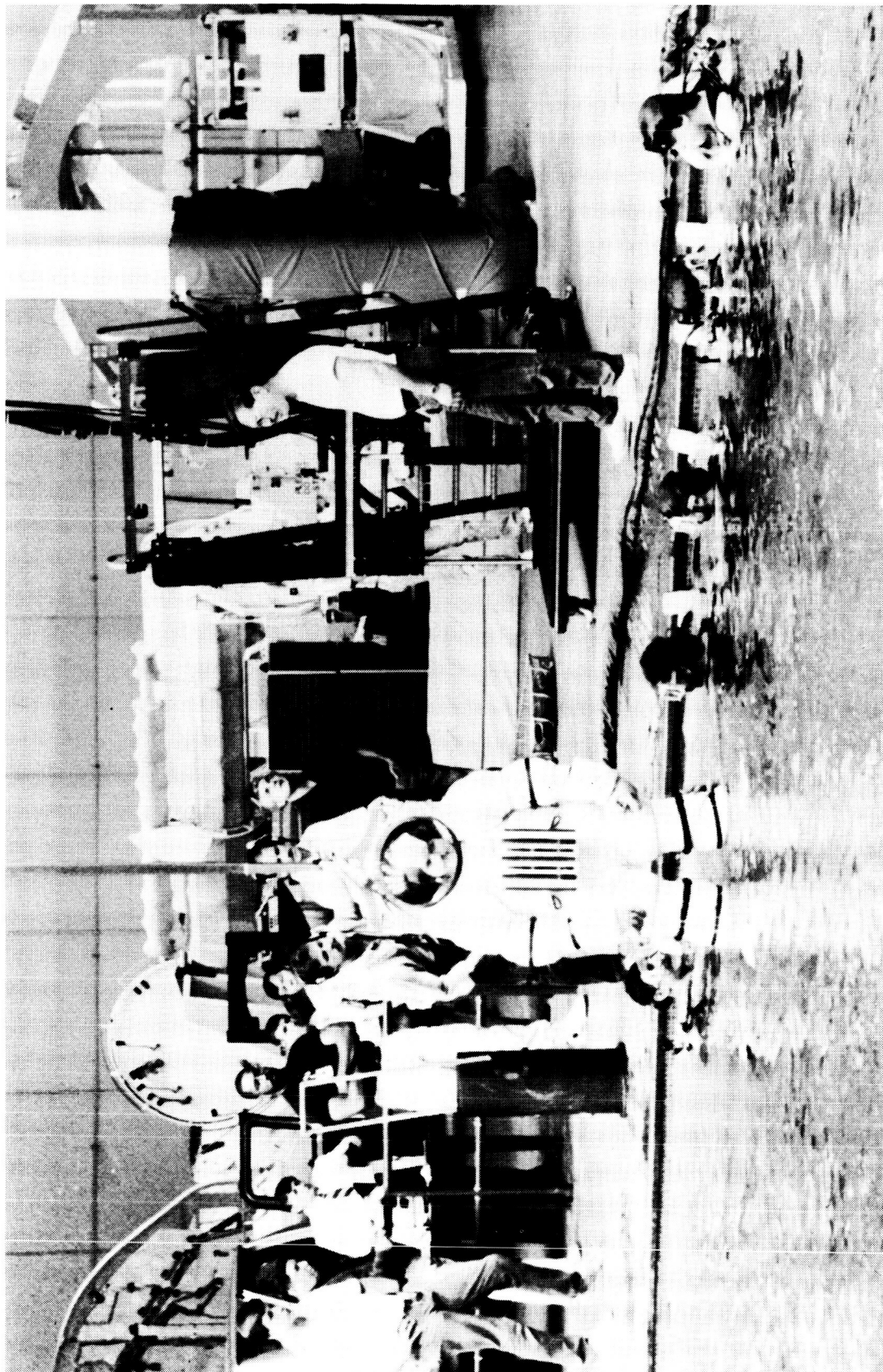
As a part of the overall evaluation process, a series of tests have been established at the Johnson Space Center to assess the performance of advanced suit concepts as compared to the current Shuttle EMU. These tests consist of mobility range comparisons, torque/force work capability, general workstation performance assessment, and the EASE/ACCESS structure assembly simulation.

In early 1988, tests of the AX-5 mobility and range-of-motion were completed in the Johnson Space Center WETF (Weightless Environment Test Facility). Although the hard date of these tests have not yet been totally analyzed for release by JSC, indications are that the AX-5 has considerably more mobility than the Shuttle EMU.

Currently, the AX-5 bearing assemblies are undergoing modification. Upon completion, tests will be resumed in mid-fall 1988 at JSC to complete the test matrix. In addition, component mobility torque and life cycle tests will be initiated at ARC to complete the performance assessment of the AX-5. Subsequent upgrades are anticipated and will be incorporated into the AX-5.

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AX-5 EVA SUIT TEST AT JOHNSON SPACE CENTER'S WETF



Laser-Based Anthropometric Mapping System

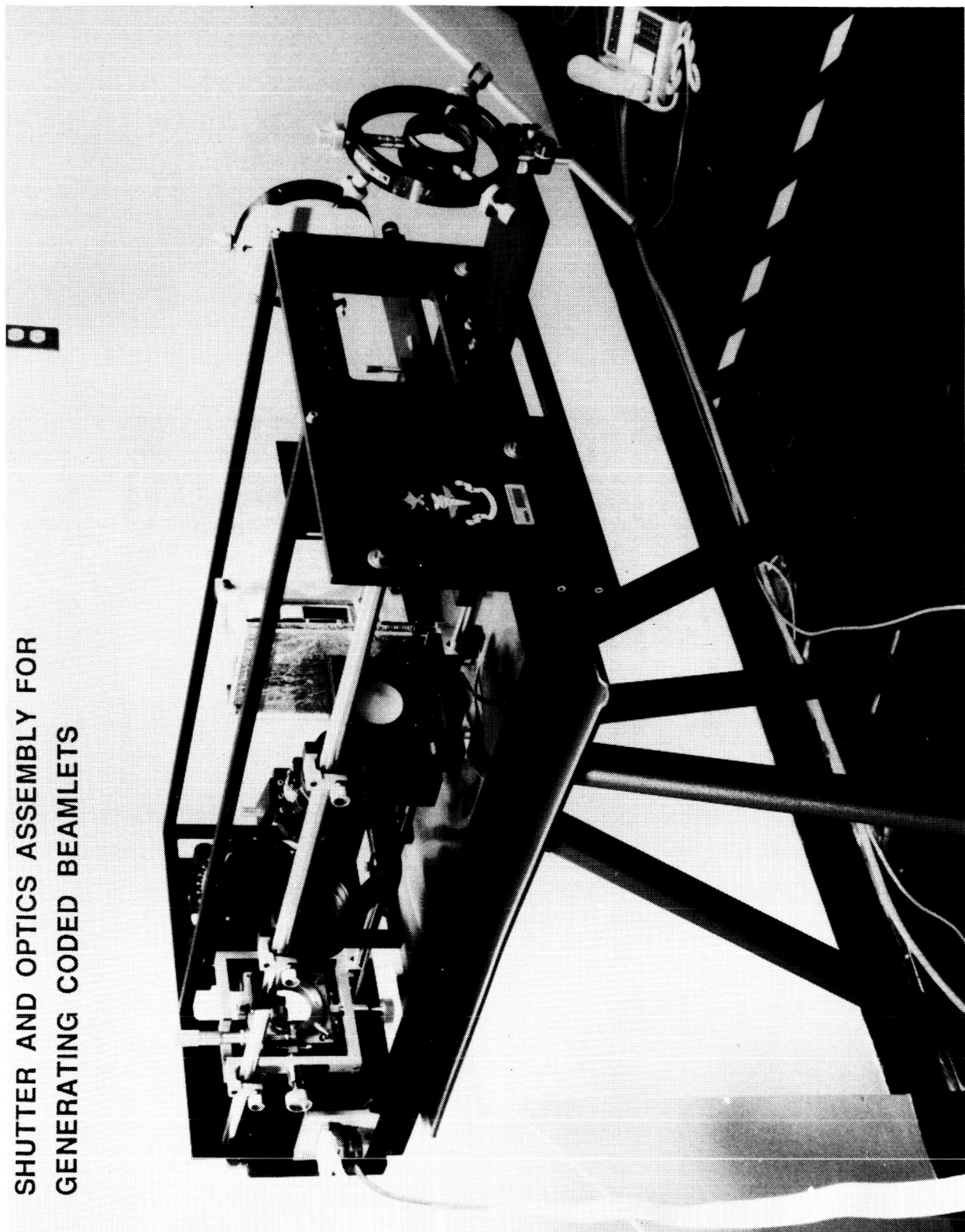
The laser-based anthropometric mapping system (LAMS) is a non-contact method for collecting three-dimensional body size data in a computer readable form. The LAMS, jointly developed with the United States Air Force, has been tested at Wright Patterson Air Force Base. It will be used to collect anthropometric data for use in spacecraft design and extravehicular mobility unit (space suit) fitting. Data from the LAMS will be included in the man-modeling anthropometric database.

The LAMS was installed at Johnson Space Center this year. Upgrades to the computer controls were made to enable more nearly autonomous operation and to take advantage of advances in computer technology over the past few years. A much smaller computer is not used to control the laser, optics, cameras, and video analyzers. The software to accept camera views taken from separate cameras, and from different points of views of the subject, has been developed at the University of Pennsylvania. It will be installed at JSC shortly.

During the next year, the system will become operational. This requires meeting all NASA safety standards and completing the first set of software for automatic data extraction. In the future, further sophistication in the data extraction will be developed.

TECHNICAL CONTACT: Barbara J. Woolford, JSC, (713) 483-3701

SHUTTER AND OPTICS ASSEMBLY FOR
GENERATING CODED BEAMLETS



Human Interface to the Thermal Expert System

The Human Interface to the Thermal Expert System (HITEX) is part of the Systems Autonomy Demonstration Project. In this project a thermal expert system (TEXSYS) will monitor, advise and diagnose faults on a thermal test bed developed by the Boeing Aerospace Corporation. The NASA Ames Human Factors Research Division (FL) is responsible for HITEX in a cooperative effort with the Information Sciences Division (RI).

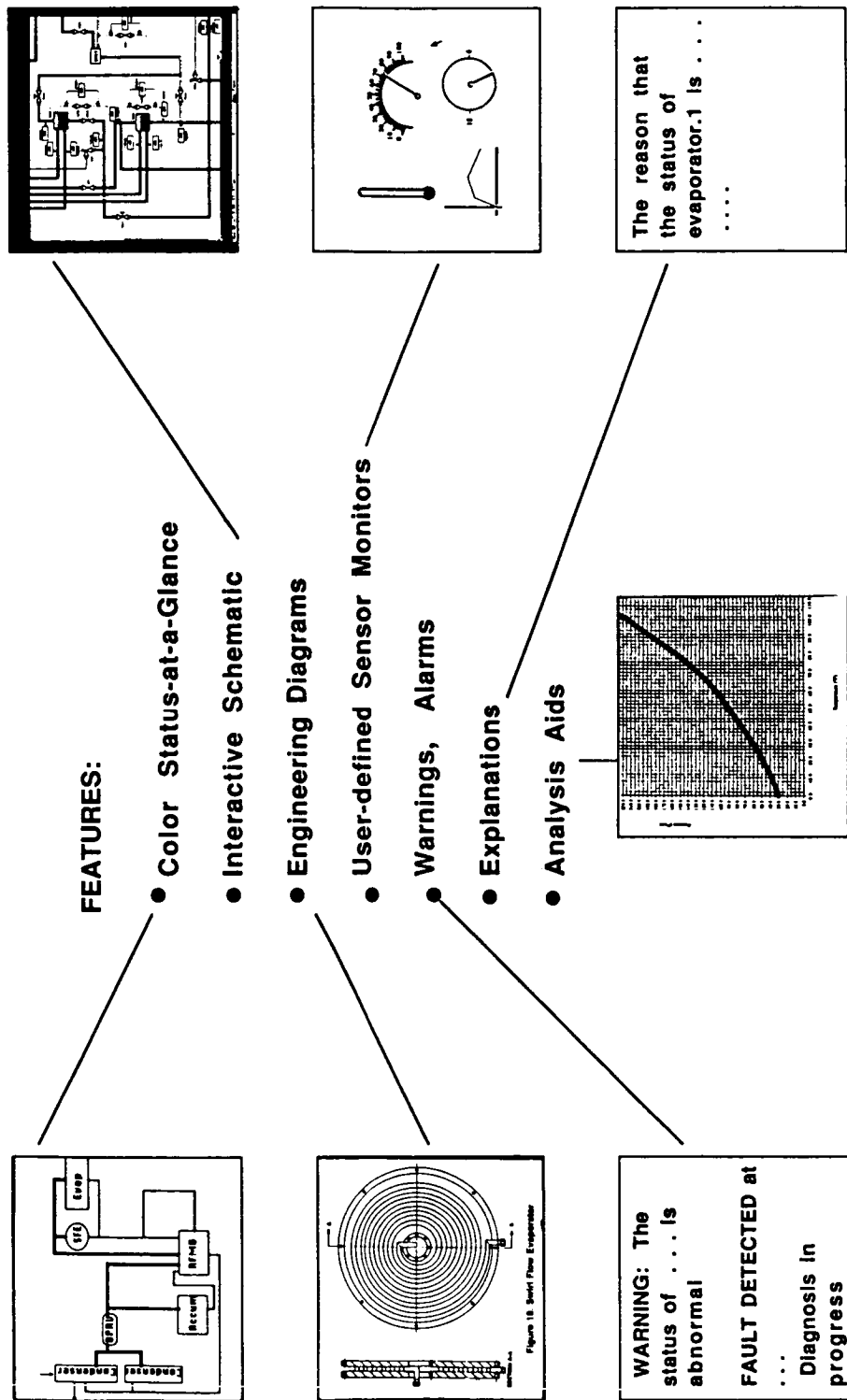
The goals of the HITEX are to provide a useful tool for thermal engineers to validate system performance, to provide flexible graphics to aid in finding and isolating information, and to accommodate users of varying skill levels. HITEX minimizes physical demands by using context-sensitive displays and customization, memory demands through immediate feedback and direct manipulation, and cognitive effort through flexible data presentation.

There are two screens with which the operator will interact: 1) the HITEX expert system screen; and 2) graphical information display. The HITEX expert system screen will be implemented on a monochrome monitor, and the graphical information display will be on a color monitor. The screens will be placed side by side, and will function as one large screen. A single keyboard and single mouse pointing device will be used, with the user being able to move the mouse from one screen to the other as if they were a single screen. Both of these screens will be driven by the one HITEX Symbolics, which will be in communication with both TDAS (Thermal Data Acquisition System) and the TEXSYS.

TECHNICAL CONTACTS: D. Foyle, ARC (415) 694-3053
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HUMAN INTERFACE FOR THE THERMAL EXPERT SYSTEM

OASIS



Human Factors - Crew Station Design

This anthropomorphic telerobot has seven dof arms and human-like hands with thumb and three fingers. The robot can be guided through an equally anthropomorphic master controller, consisting of an arm harness and a glove controller. The robot has dexterous manipulation capabilities, provided by the operator who just simply performs the desired operations manually, creating man-equivalent telepresence. The operator receives sensory feedback in user friendly form to guide him in his control and decision making process. A state-of-the-art electronics design is being implemented, which was derived from previous telerobot control systems that were pioneered here at NASA/JPL. Much effort is placed in making this telerobot system space adaptable. It is designed modular for easy transportation and storage. The harness-type controller is worn by the astronaut, allowing him mobility while eliminating any disturbing recoiling effects that hinder operations in a zero-G environment. The controller requires no independent space or modifications in the shuttle's aft flight deck.

Future space work will require dexterous robots with man-equivalent capabilities to execute unstructured tasks such as construction, servicing, material handling, contingency and emergency operations. This development could fill the immediate need to have advanced robotics capabilities available for space station assembly. The robot is guided either by IVA from the shuttle's aft flight deck or by a ground station controller to unload and assemble space station parts brought in by unmanned vehicles. Robot control could subsequently be shared with a space station-based control system.

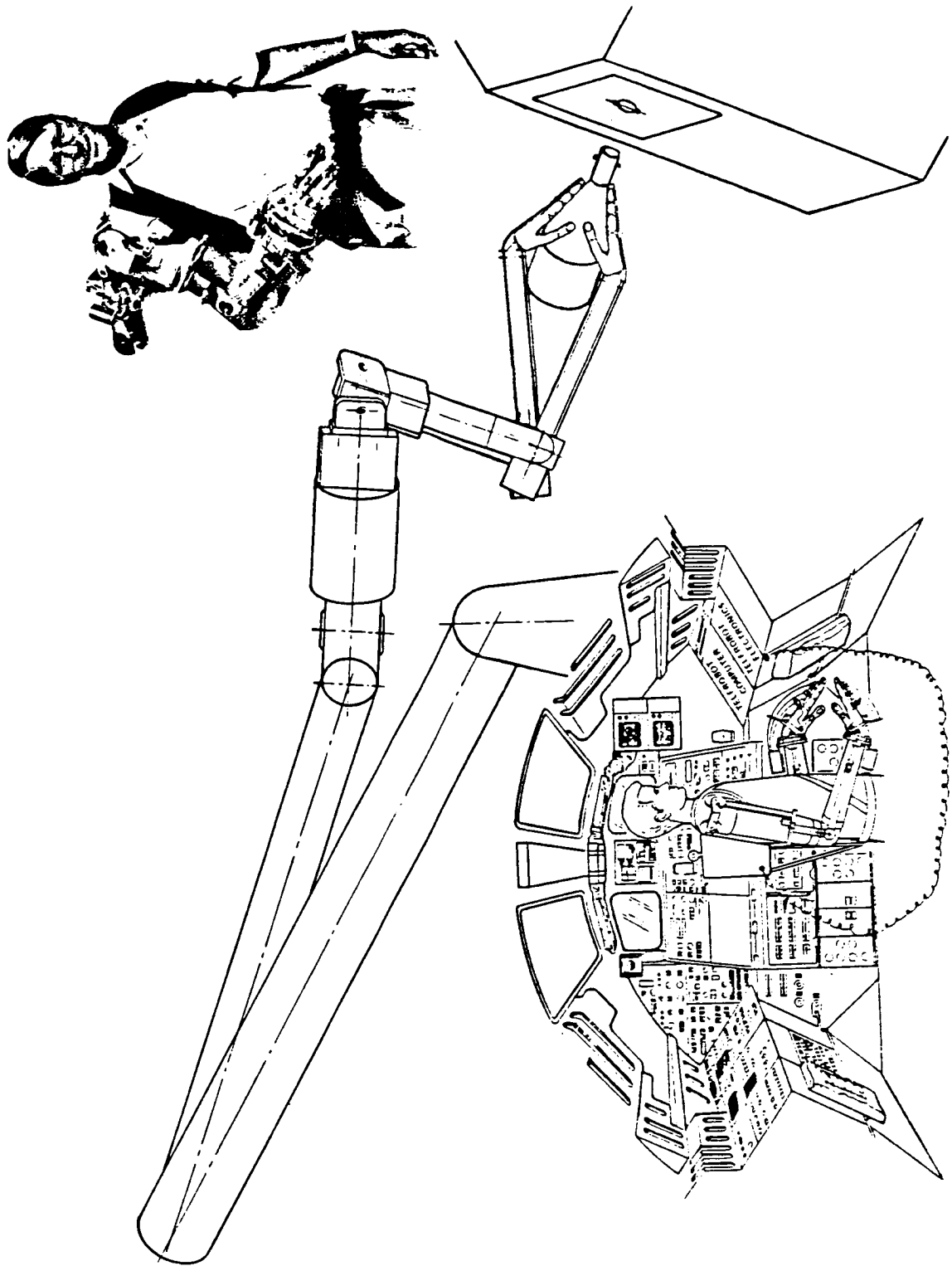
This anthropomorphic robot provides man-equivalent capabilities for executing complex, dexterous on-line manipulations in real time, geared particularly to unstructured or changing tasks where preprogrammed or autonomous control is not feasible. Its user friendly controller allows manipulations in a natural way to which the operator's brain can easily relate thus sidestepping the complex control and programming problems. EVA rules require one RMS operator and two astronauts working together for any EVA tasks and do not allow space walks within the first 3 days of a mission. The anthropomorphic robot system can be used any time, resulting in increased productivity at significant cost savings since one crew member can operate the RMS and the anthropomorphic robot.

The development of the anthropomorphic master arm nears completion. Initial breadboard testing of the electronics is scheduled to take place within this fiscal year. FY89 tasks will be to complete the first master arm and the design/partial construction of the first slave arm.

TECHNICAL CONTACTS: A. Bejczy, JPL, (818) 354-4568
B. Jau, JPL, (818) 354-4695

HUMAN FACTORS - CREWSTATION DESIGN

OAS-T



Sensor Systems

The objective of the Sensor Technology Program is to provide necessary expertise and technology to advance space remote sensing of terrestrial planetary and galactic phenomena through the use of electromagnetic and electro-optic properties of gas, liquid, and solid state materials technology.

The Sensor Technology Program is divided into two subprograms: a base research and development part and a Civil Space Technology Initiative (CSTI) part. The base research and development consists of research on artificially grown materials such as quantum well and superlattice structures with the potential for new and efficient means for detecting electromagnetic phenomena. Research is also being done on unique materials and concepts for detector components and devices for measuring high energy phenomena such as UV, x- and gamma rays that are required observables in astrophysical and solar physics missions. The CSTI program is more mission driven and is balanced among four major research and development disciplines: (1) detector sensors; (2) submillimeter wave sensors; (3) LIDAR/DIAL sensors; and (4) cooler technology. The first discipline plans to develop large spatial imaging format arrays in the near (1 - 30 μm wavelength) and far (30 - 200 μm wavelength) infrared portions of the electromagnetic (EM) spectrum. These goals are crucial to enable spaceborne remote sensing for the various terrestrial, planetary, and astrophysical missions. The submillimeter discipline is dedicated to developing the technology to enable heterodyne receiver instruments for remote sensing in the 300 to 3,000 GHz frequency regions of the EM spectrum with a focus on developing local oscillators, frequency mixers, and quasi-optical technology in this region. Backward wave oscillators, lasers, and quantum well devices may also have potential as oscillators. In the third area the acronym DIAL/LIDAR (DIAL means Differential Absorption LIDAR while LIDAR means Light Detection and Ranging) consists of research on techniques for enabling active remote sensing in which a coherent source such as a laser is used to probe the environment. Research is concentrated on technology for obtaining tunable, frequency stable, and pure space qualifiable lasers. Finally, in the last discipline research is being done on technology to enable cryogenic coolers in the Kelvin to sub-Kelvin temperature regions in support of the efforts in the detector and submillimeter wave sensor thrusts. Work includes research on various cooler concepts such as the pulse tube, adiabatic, Helium 3, and zero-gravity refrigerators and their corresponding component development.

PROGRAM MANAGER: Martin M. Sokoloski
 NASA/OAST/RC
 Washington, DC 20546
 (202) 453-2748

Low-Background Characterization of IR Arrays

Advanced infrared (IR) detector arrays have been pushed to new levels of sensitivity in an extended test and characterization program at Ames Research Center. For ultimate applications in cryogenically-cooled orbiting infrared telescopes such as the Space Infrared Telescope Facility (SIRTF), one must characterize and, in many cases, develop novel ways of operating integrated IR array devices. Preliminary tests were carried out on an OAST-developed antimony-doped silicon (Si:Sb) array and a gallium-doped silicon (Si:Ga) array, both on 58-x 62-element direct readout (DRO) multiplexers from Santa Barbara Research Center and the Hughes Microelectronics Center. (The Si:Ga array was provided on loan from GSFC when it became apparent that our test setup and software would allow the device to be characterized quickly for the SIRTF Infrared Array Camera team.)

The primary significance of this work is that new standards of performance for this technology have been achieved. With a very low background dewar and a flexible microcomputer-based drive and readout system, results have been obtained that approach and in some cases already exceed SIRTF development goals. Tests have included read noise and a breakdown of the components of read noise, responsivity, dark current, power dissipation, well capacity, transient and radiation effects, and others. As an illustration of pushing array performance beyond expected limits, the vendor initially projected that read noise of about 150 rms electrons (e^-) might be achieved with this technology, we have consistently achieved a read noise level of $<40e^-$, through optimum clocking, reduction of noise on DC bias lines, and proper grounding techniques. Many of these tests were for the first time performed under realistic SIRTF conditions, e.g., 200 s integration times and <1000 ph/s backgrounds. In the great majority of cases, excellent performance was obtained. This provides important experimental evidence of the extraordinary potential of integrated IR array technology on SIRTF. Key state-of-the-art results included $<40e^-$ read noise, $2e^-/s$ of dark current (Si:Sb at 5 K), and low power dissipation (0.6 mW for the entire 3596-element array).

In a significant enhancement to our ability to simulate the space environment, a new radiation effects facility became operational at ARC in FY88. We now have the ability to test with ^{241}Am (60 keV gamma), ^{137}Cs (662 keV gamma), and ^{55}Fe (6 keV x-ray) sources. Initial gamma tests with the Si:Ga array indicated favorable response. Virtually no charge-blooming or spillover behavior was observed.

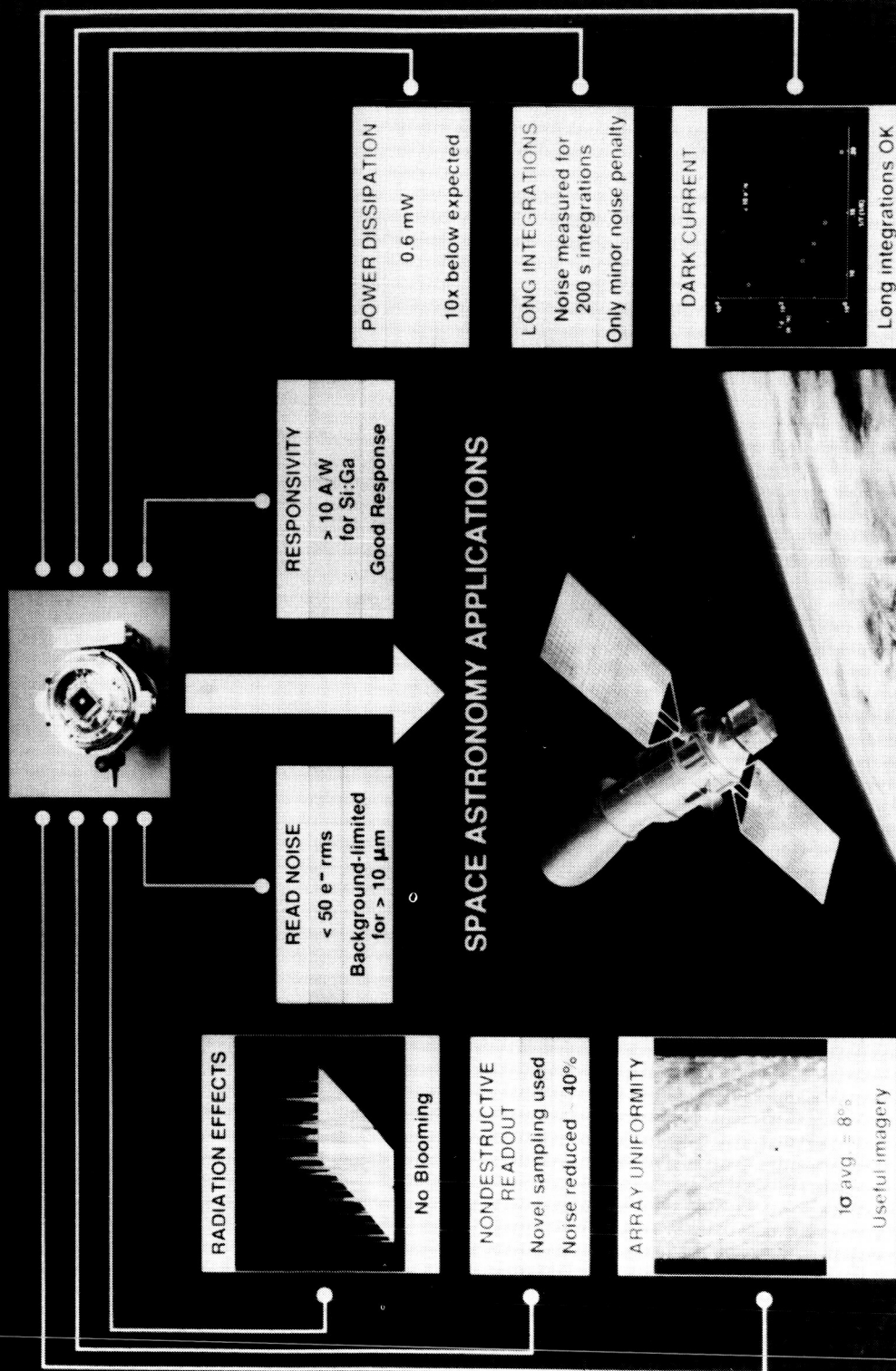
At this point, the characterization is about two-thirds complete. Emphases for the near future include more complete radiation tests, a check of imaging properties, use of novel sampling techniques (nondestructive readout), and continued parallel development of impurity-band conduction detectors for improved temporal and radiation response.

TECHNICAL CONTACT:

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EXCELLENT LOW-BACKGROUND IR ARRAY PERFORMANCE

SBRC Si:Ga and Si:Sb 58 x 62 ARRAY EVALUATIONS AT ARC



Helium-3 Cooler

A ^3He cooler has been constructed for use in rocket-borne infrared astronomy and in zero-g physics experiments. The cooler has no moving parts. The working fluid is ^3He (a rare isotope of helium). The cooler uses a heater-activated sorption pump that contains activated charcoal. The cooler is started by heating the pump. This drives off the ^3He , which is condensed into the sintered copper in the evaporator. The sinter retains the liquid in zero gravity by surface tension forces. At this point, the heater is turned off allowing the pump to re-adsorb the ^3He thus producing evaporative cooling in the evaporator. Temperatures down to 0.25 K can be reached starting from a 1.5-2 K heat sink provided by a superfluid helium bath.

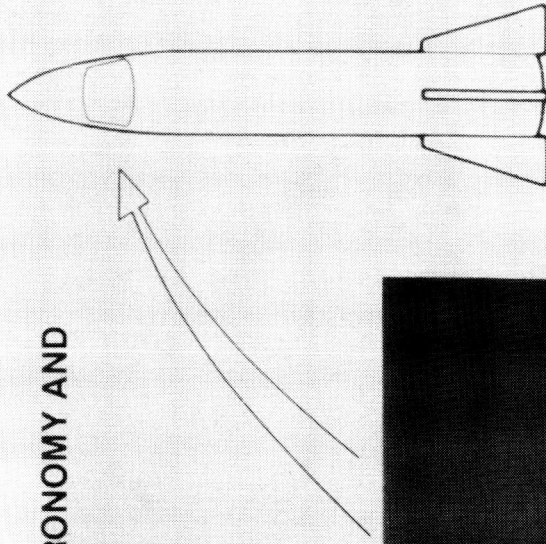
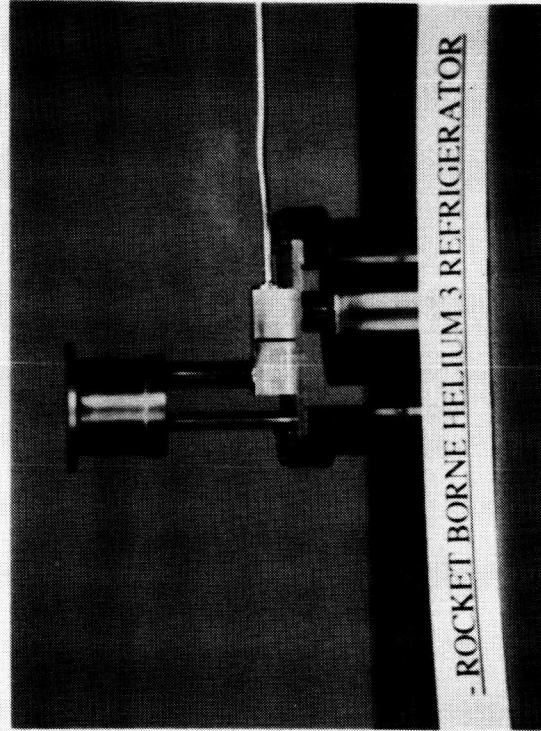
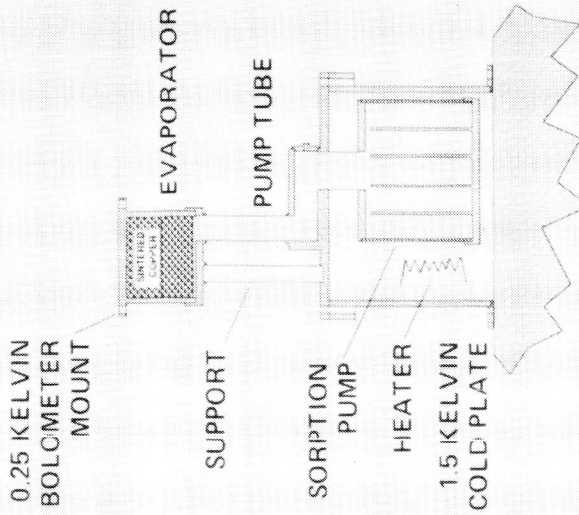
The surface tension (capillary) confinement of cryogens for space applications is a technique that has been pioneered by NASA Ames. By lowering the temperature available in a zero-g environment from the 1.5 K region provided by superfluid helium (as in IRAS) to 0.25 K, this cooler allows a $\times 10 - \times 50$ improvement in bolometer sensitivity and also permits the study of critical phenomena at the $^3\text{He}/^4\text{He}$ tricritical point. The cooler has no moving parts, hence it is inherently long lived. The operation is controlled by a single heater, hence control is simple. The cooler is simple to incorporate into a superfluid helium dewar as it may be bolted to the superfluid-cooled cold plate and only needs a few electrical leads for control and monitoring.

This cooler is scheduled for flight testing in a sounding rocket in February 1989. This will be the first flight test of a sub-kelvin cooler in zero-g.

TECHNICAL CONTACT: Peter Kittel, ARC (415) 694-4297

HELIUM - 3 COOLER

^3He COOLER FOR ROCKET-BORNE INFRARED ASTRONOMY AND
ZERO-G PHYSICS EXPERIMENTS



Spaceborne Laser Ranging and Altimetry Components

The objective of this program is to develop subsystems and components in support of future NASA laser ranging and altimetry missions such as the Geodynamics Laser Ranging System (GLRS) facility on Eos. Current emphasis is placed upon two critical GLRS components: 1) a diode-pumped, subnanosecond pulse Nd:YAG laser transmitter; and 2) a space-qualified, 2 ps resolution-streak camera for precise timing.

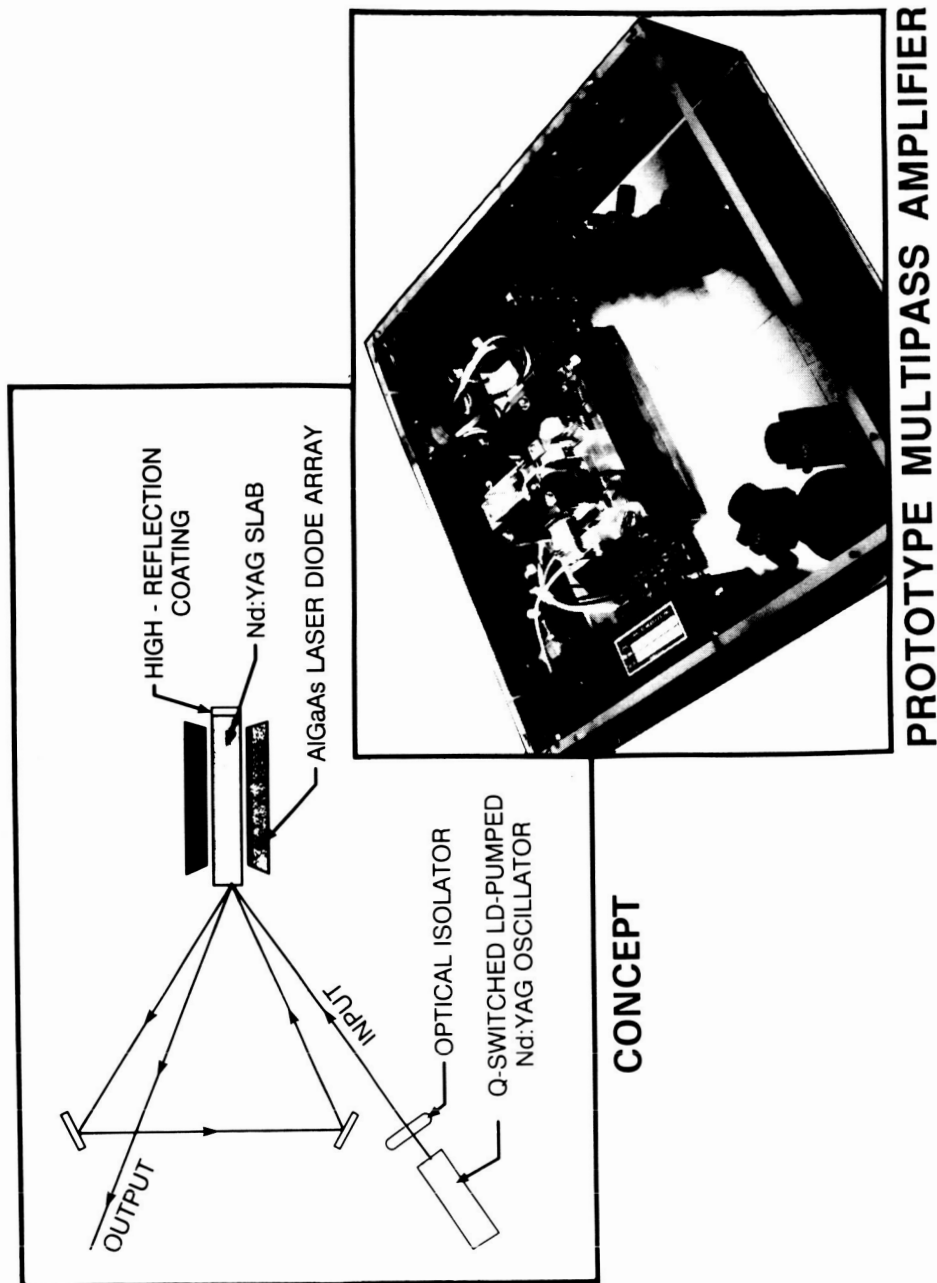
Current NASA programs in geodynamics rely heavily on ground-based technologies such as Satellite Laser Ranging (SLR) and Very Long Baseline Interferometry (VLBI). Although these systems have produced highly accurate and valuable data for global geodesy and tectonic plate motion studies, their high fabrication and operating costs necessarily limit the number of geodetic points that can be monitored at any given time. An orbiting spaceborne laser ranger, making precise distance measurements to a large number of passive ground-based targets, would provide the spatial and temporal resolution required for highly accurate modeling of tectonic plate motion and regional crustal deformation leading perhaps to a reliable predictor for earthquakes. Subnanosecond pulse lasers and picosecond resolution-streak cameras are required to achieve the required subcentimeter accuracies. The ranger utilizes the second and third harmonics of the Nd:YAG transmitter to perform the range measurements. The time delay introduced between the two colors by atmospheric dispersion is measured by the streak-camera receiver to convert time-of-flight to a subcentimeter accuracy distance measurement. The residual Nd:YAG energy is used in a high-precision altimeter for applications in geology, ice processes, and cloud physics.

Concepts for the transmitter and streak-camera receiver were developed during this first year of the program and hardware is being procured for prototype development and testing. In the transmitter, a 100 ps pulse is generated at 1,064 nm by an AlInP diode laser and injected into a Nd:YAG regenerative amplifier to produce approximately 1 mJ of energy. The pulse is then amplified tenfold in a multipass Nd:YAG preamplifier. In order to achieve maximum efficiency, the amplifiers are pumped at 810 nm by AlGaAs diode arrays. During FY88, theoretical calculations of the overall laser efficiency were made, the ultrashort pulse AlInP diode laser was delivered, a contract was awarded for the delivery of 10 linear AlGaAs diode-pump arrays, the multipass amplifier was designed and assembled, a contract is near award for the design of a space-qualified streak camera, and two onsite contractors were hired to support the design of the regenerative amplifier and streak-camera optical front end.

TECHNICAL CONTACT: Dr. John J. Degnan, GSFC, (301) 286-7714

DIODE-PUMPED MULTIPASS Nd:YAG LASER AMPLIFIER

OASIT



Tunable Infrared Lidar

The objective of this program is to investigate passive nonlinear optics techniques for generating continuously tunable coherent infrared laser radiation in the wavelength region between 2 to 25 μm . Specifically, this program investigates the Resonance Enhanced Stimulated Raman Scattering (RESRS) of frequency-doubled Alexandrite radiation in cesium atomic vapor and sequential Stokes Scattering of Alexandrite radiation in high-pressure hydrogen cells.

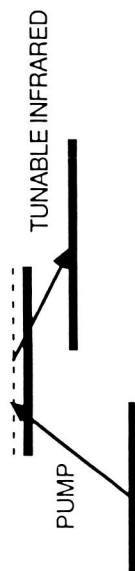
Since most atmospheric molecules of interest have easily identifiable vibration-rotation absorption lines in the wavelength band between 2 to 25 μm , the latter is often called the "molecular fingerprint region." Furthermore, the existence of atmospheric transmission windows in this same band permits remote sensing of tropospheric trace species from spaceborne platforms. Past lidar systems have often relied upon the fortuitous overlap of a narrow laser wavelength with one or more narrow absorption features. The recent development of highly tunable vibronic solid-state lasers permits highly tunable operation in the near infrared. The nonlinear Raman process permits this wide tuning range to be shifted deeper into the infrared through totally passive means to support other trace species measurements important to NASA programs in atmospheric chemistry.

To date, extensive theoretical analysis and computer modeling of the RESRS process in cesium vapor has been carried out under a grant to Brown University resulting in several publications during FY88. Analytic density matrix solutions with arbitrary parameters have been obtained for the three-level RESRS problem. Numerical modeling of the nonlinear equations governing pump beam propagation has been completed. In addition, experiments on the analog propagation system of laser-pumped ruby have revealed that the numerically predicted ring formation actually occurs. Further experiments on the statistical fluctuations associated with stimulated Raman scattering and the effects of external seeding are under investigation at Brown. The theoretical calculations are being used to predict the optimum operating parameters for efficient infrared conversion and maximum tunability in in-house cesium vapor RESRS experiments currently underway at GSFC. During FY88 the Alexandrite doubling efficiency in an autotracking second-harmonic generator was increased from 3% to 16%, which allowed reaching the expected Raman threshold for RESRS. Also in FY88, a hollow waveguide sequential Stokes Raman cell (that uses undoubled Alexandrite as the pump) was designed and is currently in fabrication. This cell greatly extends the nonlinear interaction region in hydrogen by confining the light in a long hollow light pipe.

TECHNICAL CONTACT: Dr. John J. Degnan, GSFC (301) 286-7714

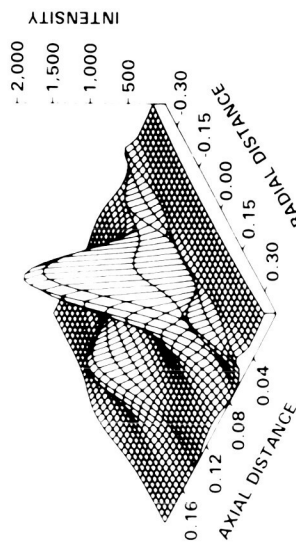
STUDIES OF RESONANCE ENHANCED STIMULATED RAMAN SCATTERING (RESRS) FOR LIDAR APPLICATIONS

EXACT SOLUTIONS FOR THE THREE-LEVEL RESONANCE ENHANCED STIMULATED RAMAN SCATTERING INTERACTION

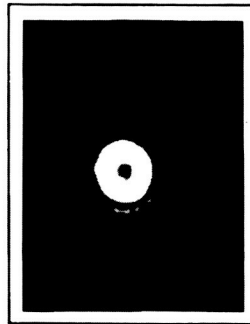


NONLINEAR BEAM PROPAGATION IN RESRS

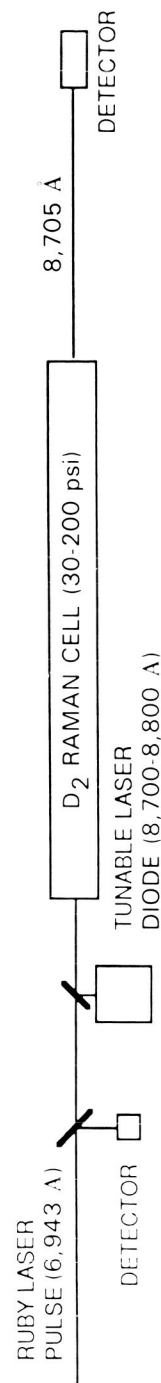
NUMERICAL SUPER-COMPUTER RESULTS



EXPERIMENTAL EVIDENCE FOR RING FORMATION IN LASER PUMPED RUBY



STUDIES OF STATISTICAL FLUCTUATIONS IN STIMULATED RAMAN SCATTERING



Technical Contact: John J. Degnan, GSFC, (301) 286-7714

Imaging X-ray and Cosmic Ray Spectrometers

There are two main objectives of this program. One is to develop an imaging x-ray spectrometer array. This array will consist of a number of pixels with high-quantum efficiency, energy resolution less than 250 eV in the 1 to 30 KeV range, and designed to preclude charge splitting between pixels. The second objective is to develop a cosmic-ray detector using a different electrode geometry to allow assembly of a large area array and simplify the readout electronics. Both types of detectors will utilize a solid-state drift chamber geometry made from high resistivity silicon.

These types of detectors should provide superior performance over those currently available. For x-ray detection, calorimeters provide good energy resolution but must operate at 1 K and are difficult to form arrays for imaging. CCDs provide good spatial resolution but have not been developed with sufficient pixel size and require shutters during readout. The drift detectors should provide both good energy and spatial resolution at 77 K. Standard IC fabrication techniques will be utilized. Therefore, fabrication of these detectors will be much more consistent compared to the previously attempted deep diodes. For cosmic-ray detection, two planes of solid-state detectors will be simpler, more rugged, and provide superior spatial resolution over current wire-chamber detectors.

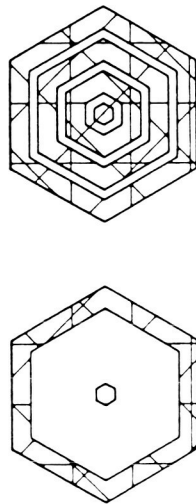
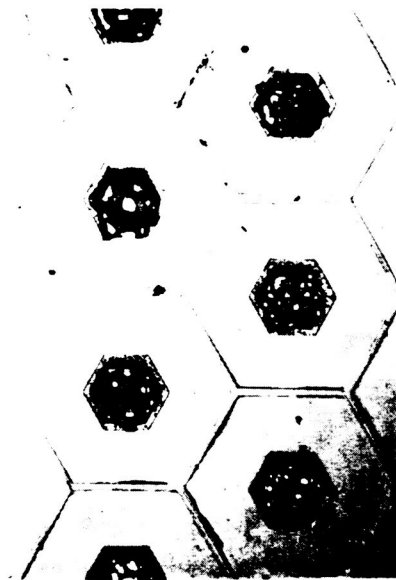
The high resistivity silicon necessary to fabricate these detectors has been procured. A first-pass mask set of x-ray detectors has been designed and obtained and will be used to fabricate detectors in-house. The design includes six different electrode geometries that will be evaluated for energy resolution. The readout electronics used will be those developed for use with the deep diode-type detectors. For cosmic-ray detection, a mask set of the design based upon the inventor's original work has been obtained, and detectors utilizing the high resistivity silicon are currently being fabricated. These detectors will be evaluated for spatial resolution on a precision x-y table. Future plans are to design an array of x-ray detectors using the best design and evaluate pixel to pixel consistency. Additionally, a second generation cosmic-ray detector will be designed specifically for large-area array applications.

TECHNICAL CONTACT: Carl Kotecki, GSFC (301) 286-4826

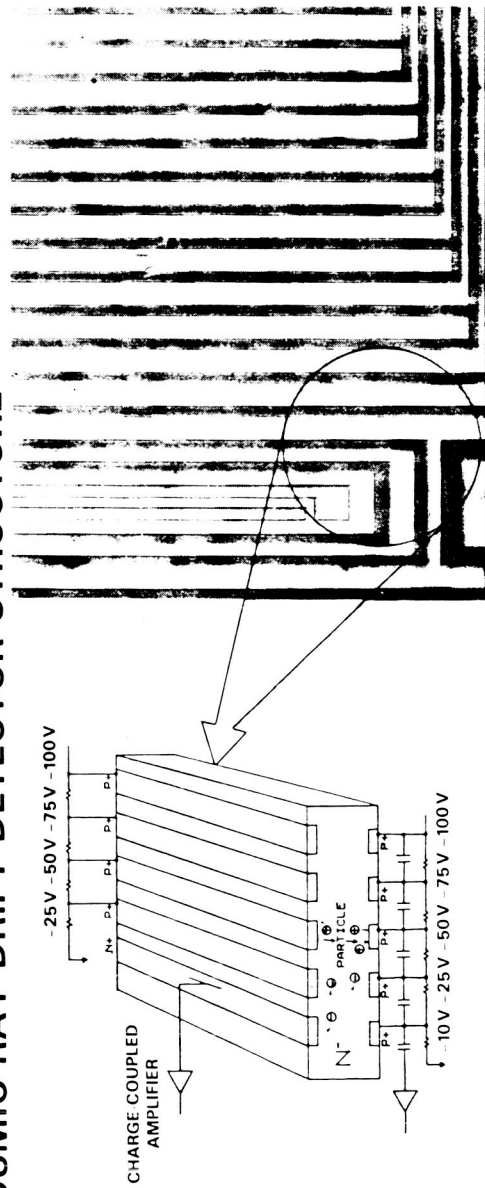
IMAGING X-RAY AND COSMIC RAY SPECTROMETERS

OASIS

X-RAY SPECTROMETER TEST PIXELS



COSMIC-RAY DRIFT DETECTOR STRUCTURE



Silicon Compatible Infrared Detector Array

The objective of this program is to develop the enabling technology for a new generation of infrared focal plane arrays, which combine the properties of large size, superior uniformity, and high quantum efficiency.

Infrared focal plane arrays are used by NASA for applications in all four space science disciplines: astrophysics, earth science, solar system exploration, and space physics. Advances in the performance of these arrays are needed to enable a variety of measurement types involving both imaging and spectroscopy.

JPL is developing a silicon compatible technology that allows the proven technology of large-area silicon multiplexors to be exploited while avoiding problems of thermal mismatch inherent to today's hybrid metal interconnect technology. The use of Molecular Beam Epitaxy (MBE) in the fabrication of these devices allows the growth of silicon and metal silicides with abrupt interfaces and in complex stacked structures. These devices have the potential for dramatically improved quantum efficiency and higher operating temperatures compared to the current generation of silicon compatible infrared arrays.

In FY87 a Schottky diode detector using epitaxial cobalt silicide as the metal was developed. In FY88 this device was modified with a thin layer containing a high concentration of the dopant gallium. This extended the cutoff wavelength of the device from 3.5 to 5.0 μm . In addition, the quantum efficiency at any given wavelength below the cutoff is significantly increased. Devices incorporating boron doping, which allows still higher dopant concentrations, will enable further extension of the cut-off wavelength.

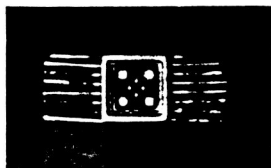
Future plans included using the epitaxial silicide layer as a template for growth of additional silicon and metal layers. Such structures, with multiple metal silicide layers are expected to have quantum efficiencies improved by substantial factors.

TECHNICAL CONTACT: Paula J. Grunthaner, JPL (818) 354-0360

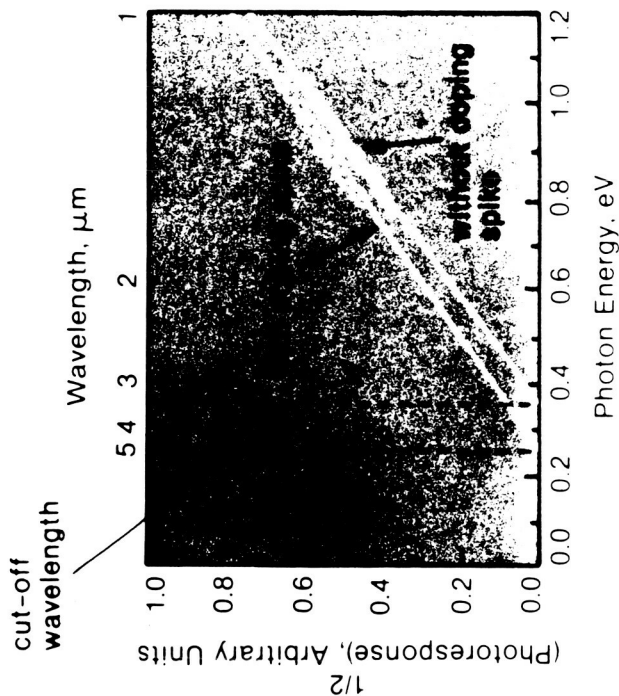
SCHOTTKY DIODE INFRARED SENSOR WITH EXTENDED CUT-OFF WAVELENGTH

OAS-T

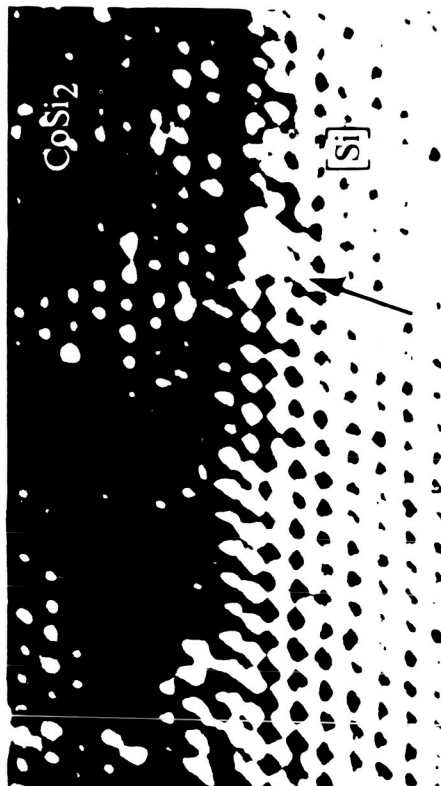
- Silicon and CoSi_2 layers are grown by Molecular Beam Epitaxy.
- Thin, p^+ layer decreases the effective Schottky barrier height, increasing the cut-off wavelength from 3.5 to 5.0 μm .
- CoSi_2 layer is single crystal. Future devices will employ multiple silicon and CoSi_2 layers.



CoSi_2
$p^+ \text{ Si}$
Intrinsic Si
$p^+ \text{ Si substrate}$



High-resolution transmission-electron-microscopy lattice image (magnification: 10,000,000X).



Photoresponse of the diodes, showing the increase in cut-off due to the p^+ layer.

Submillimeter Heterodyne Sensors

The objective of this program is to develop space qualifiable superconducting tunnel junctions for use in heterodyne radiometers.

Heterodyne radiometers are employed in remote sensing applications that require high sensitivity and resolving power such as spectroscopic observations of the earth's atmosphere, planetary atmospheres, and the interstellar medium. The important fundamental rotational and vibrational transition of the more abundant molecules including OH, HD, H₃⁺, and HCl occur at submillimeter wavelengths and can be used to measure composition, temperature, and velocity of these species. Applications range from investigation of ozone depletion in the earth's atmosphere to the study of star forming regions in the galaxy.

JPL is developing single heterodyne mixers and arrays of mixers based on superconducting niobium nitride (NbN). These devices are projected to operate at frequencies up to 3 THz, at temperatures up to 8K with superior sensitivity. In the four years since this program was established JPL has established a position of national leadership in NbN technology.

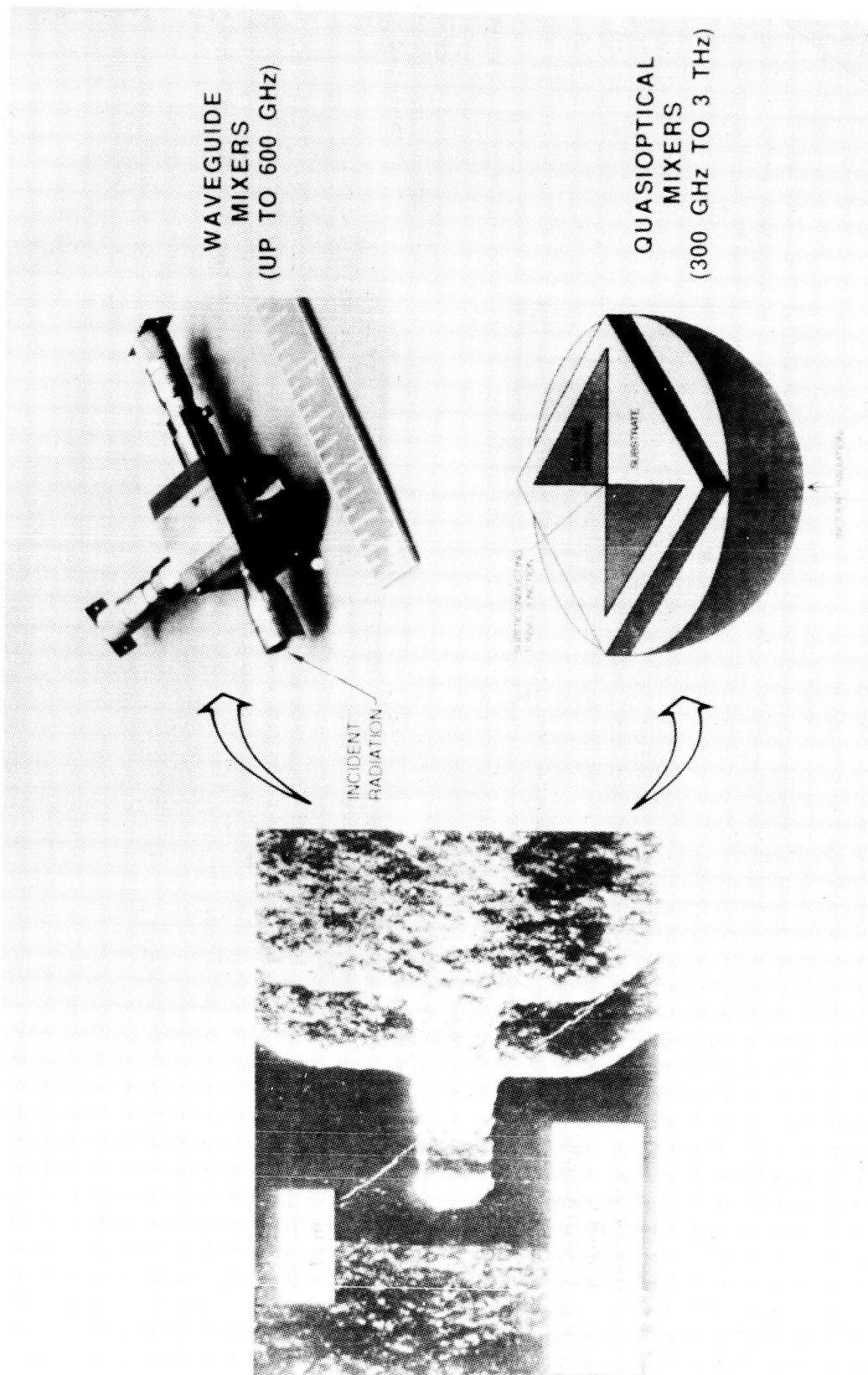
In FY86 JPL demonstrated NbN-MgO-NbN junctions with superconducting transition temperature (Tc) of 17 K. In FY87 the first small area junctions (2 μm x 2 μm) were fabricated. This year (FY88), small area junctions with very high current densities have been fabricated ($J_c = 100\text{-}10,000 \text{ A/cm}^2$) and an innovative radiation coupling technique has been conceived for improving heterodyne sensitivity. The first observation of heterodyne detection in NbN tunnel junctions was made at 200 GHz in May 1988.

Future plans include the further development of devices and mixers to meet the goal of demonstrating superior heterodyne performance at 600 GHz by FY91.

TECHNICAL CONTACT: Margaret Frerking, JPL (818) 354-4902

SUBMILLIMETER HETERODYNE SENSORS RADIATION COUPLING TECHNOLOGY

QASJ



Submillimeter Wavelength Backward-Wave Oscillator

The purpose of this program is to develop the technology for a series of backward-wave oscillators (BWO) for the frequency range 500 to 2000 GHz. These electron beam tubes will be used as local oscillators in heterodyne receiver/spectrometers.

Because tube dimensions scale with wavelength, traditional methods of machining the slow wave structure of the BWO are not possible. A photolithographic method was developed to etch the circuit onto a diamond substrate. Diamond is a superb dielectric and has a thermal conductivity five times greater than copper that will provide superior heat transfer.

Other innovations include a high conversion efficiency circuit (the interdigital line), not previously used in oscillators at this wavelength, and research on long-lived cathodes. This will result in longer lifetimes, less thermal loading of the circuit and smaller magnetic focusing fields. Because the period of the etched circuit can be very small, lower beam voltages are possible.

Local oscillator noise is a major consideration in heterodyne receiver design. It is probably that transverse energy in the electron beam is a major source of BWO noise and transverse energy increases with beam compression. The tubes presently being built should offer a reduction in noise because the gun is designed for only moderate beam compression.

A 400-600 GHz prototype BWO was built and tested. Weak signals were detected but could not be positively identified as "BWO radiation." The output coupler seemed to be the culprit and a new circuit was designed for 250 GHz, a frequency where the coupler was known to work. Oscillations over the frequency range of 200-265 GHz were immediately observed. The output power was estimated to be in the 50-100 microwatt range.

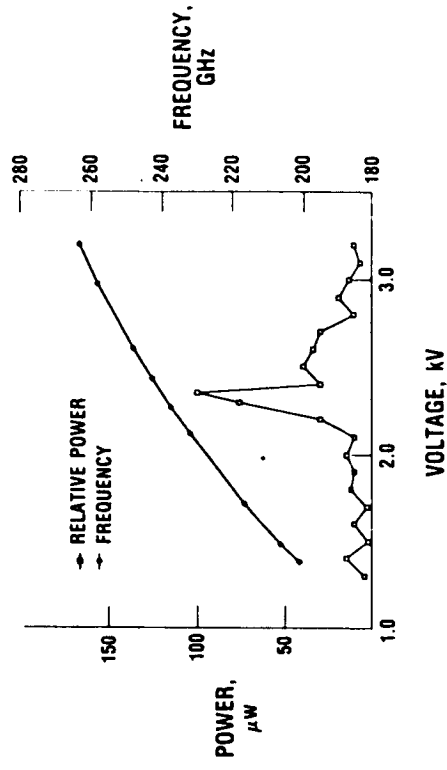
A new output coupler has been designed and incorporated into the interdigital line circuit. This coupler will enable quasi-optical coupling with a sapphire hyper-hemispherical lens system. Two new circuits have been fabricated at Lincoln Laboratories. One circuit was sent to the University of Utah for incorporation into their laboratory BWO, and the other will be used in experiments at LeRC. It is expected that the new output coupler will result in output powers in the milliwatt range.

TECHNICAL CONTACT: Norbert Stankiewicz, LeRC (216) 433-3674

SUBMILLIMETER WAVELENGTH BACKWARD WAVE OSCILLATOR

ACCOMPLISHMENTS

- DEMONSTRATED PROTOTYPE PERFORMANCE FROM 200 TO 260 GHz
- FREQUENCY IS VOLTAGE TUNABLE
- BEAM VOLTAGE RANGE 1.4 kV to 3.0 kV
- BEAM CURRENT 0.5 mA
- MICROFABRICATION OF SLOW WAVE CIRCUITS



DESIGN PROJECTIONS

- FREQUENCY UP TO 2000 GHz
- LIFE UP TO 100,000 HOURS
- POWER INPUT LESS THAN 10 WATTS
- WEIGHT OF 0.5 KG
- STABLE PHASE LOCK CAPABILITY
- 1: 10,000,000

IMPACT

- ONLY CONTINUOUSLY TUNABLE LOCAL OSCILLATOR CAPABLE OF SIGNIFICANT POWER AT SUBMM WAVELENGTHS
- ENABLING TECHNOLOGY FOR SPACE BASED SPECTROSCOPY

RC89-314(3)

Ti:Al₂O₃ Laser and Nd-Based Pump Technology

The objectives of this research are to: 1) demonstrate a Ti: Al₂O₃ laser that produces 1.0 J/pulse at a 10 Hz pulse repetition frequency and is tunable over the H₂O absorption features around 0.73 and 0.94 μ m and the O₂ absorption features around 0.76 μ m; and 2) demonstrate a frequency-doubled Nd-based laser that can be used for aerosol measurements as well as a pump for the Ti:Al₂O₃ laser.

Demonstration of these systems would prove the feasibility of utilizing these space qualifiable lasers for LIDAR measurements of aerosol concentration, H₂O concentration, and pressure and temperature. In addition, the state of the art would be significantly advanced, both in Ti:Al₂O₃ performance levels and in the laser diode-pumped Nd-based laser field. Finally, both engineering and reliability data would become available for the design of these systems for flight hardware.

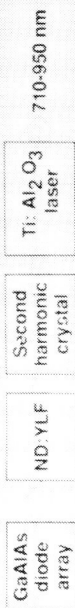
Significant advances in the state of the art have been accomplished at NASA Langley Research Center. Among these accomplishments are: 1) demonstration of partial injection locking of a Ti:Al₂O₃ laser using a laser diode as the injection source; 2) a model for a self-injection locked Ti:Al₂O₃ laser has been developed and experimentally verified; 3) a model for a Ti:Al₂O₃ laser amplifier including loss at the laser wavelength has been developed and experimentally verified; 4) a line width of 0.4 pm has been demonstrated; 5) a small signal gain of 25 as well as a large signal gain of three have been demonstrated; 6) and a model of the amplified spontaneous emission has been developed.

Schwartz Electro-Optics has made significant progress on Ti:Al₂O₃ lasers under a NASA Langley contract. Among the accomplishments are the design of a 0.5 J/pulse Ti:Al₂O₃ laser, installation of a frequency doubled Nd:YLF laser for pumping, and the achievement of continuous wave operation of an AR ion pumped Ti:Al₂O₃ laser. Sanders Associates designed and built the Nd:YLF laser installed at Schwartz Electro-Optics.

NASA Langley is also investigating the laser diode-pumped Nd-based Laser concept. Absorption spectra for six candidate Nd laser materials were obtained, digitized, and stored in Langley's database. An absorption efficiency program was written to calculate the absorption efficiency of these six laser materials. In addition, the storage program was written to calculate the absorption efficiency of these six laser materials. In addition, the storage efficiency and extraction efficiency were calculated. The best candidate for laser diode-pumped Nd laser materials, Nd:YLF, is the laser material with the highest product of these efficiency calculations. NASA Langley is also cooperating with the Navy and the Army in a series of contracts with industry to demonstrate a frequency doubled laser diode-pumped Nd-based laser capable of producing 0.5 J/pulse at a 10 Hz pulse repetition frequency.

TECHNICAL CONTACT: Dr. Norman P. Barnes, LaRC (804) 864-1630

Ti: SAPPHIRE LASER DEVELOPMENT

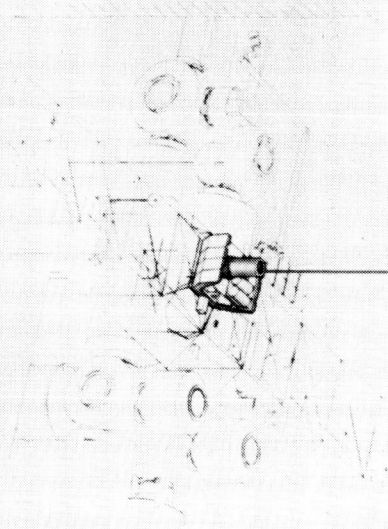


NASA DOD Sanders U-of Rochester Schwartz E-O

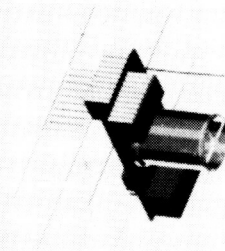
Goals:

- 0.5 Joules - scalable to > 1.0 Joules
- 10Hz rep. rate
- 75% efficiency
- Tunable from 710-950 nanometers

TALOS ON SPACE STATION



EAGLE/LASA ON EOS



Demonstrated:

- Partial diode injection locking
- Self-injection locking
- Model verified
- Model of amplified spontaneous emission verified
- 0.4 pm spectral bandwidth

Nonlinear Optics in the Mid-Infrared

Using nonlinear optical devices, a solid-state laser operating in the region between 1.5 and 2.1 μm can be converted into a tunable laser source covering the 2.5- to 12.0- μm region. Solid-state lasers with operating wavelengths longer than 2.1 μm are relatively uncommon and usually not tunable. Consequently, having a nonlinear optical device to convert the laser radiation to any desired longer wavelength in an efficient manner becomes crucial.

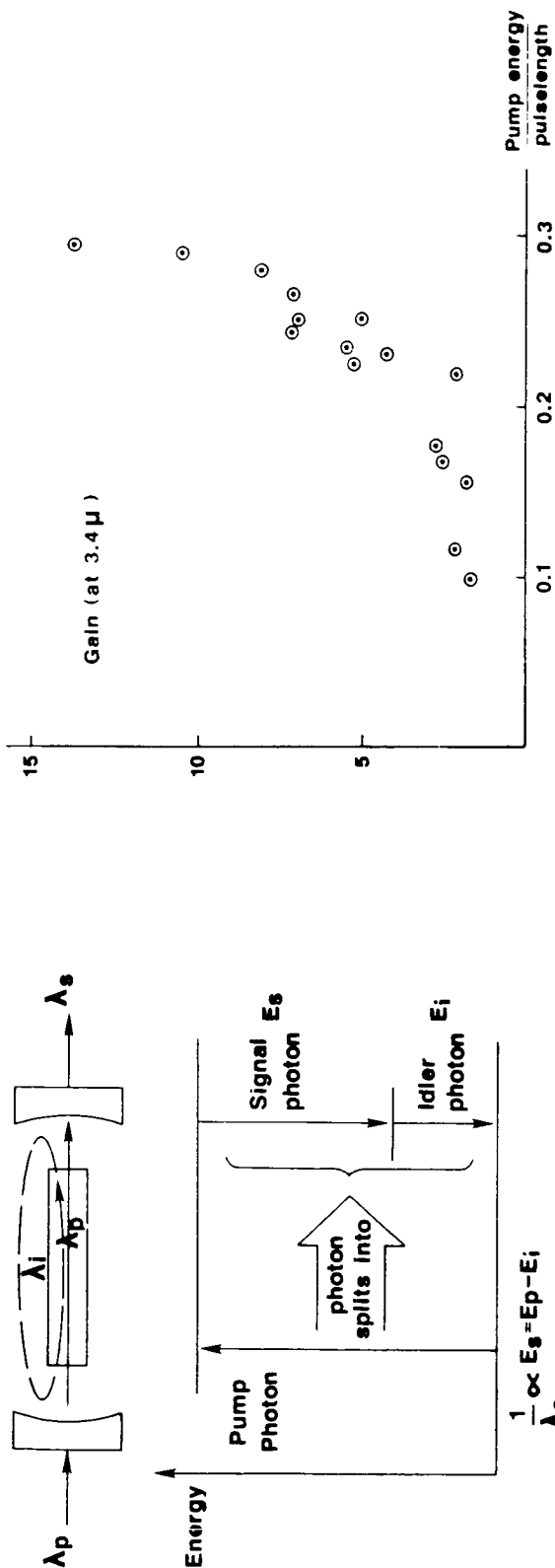
Demonstration of a high gain has obvious positive implications on the efficiency of any nonlinear optical device used to convert the laser radiation to longer wavelengths. Optical parametric amplifiers are devices that can convert laser radiation to longer wavelengths. With a high enough gain, and low enough loss, an optical parametric amplifier can become an optical parametric oscillator by adding a set of mirrors to the device. NASA Langley has demonstrated an optical parametric amplifier with a gain in excess of 13. To achieve this, a AgGaSe_2 nonlinear crystal was used. An Er:YLF laser operating at 1.73 μm provided the pump laser. A curve of the gain as a function of the quantity $(E_p/\tau_p)^{1/2}$ shows the characteristic hyperbolic cosine squared dependence. In this expression, E_p is the pump energy and τ_p is the pump pulse length.

While optical parametric amplifiers and oscillators have been demonstrated before, attainment of a gain of 13 is believed to be the highest yet achieved with these materials. Typically, the output of an optical parametric oscillator has been erratic due to the small gain of the device. If the device is operated well over threshold, the operation tends to be much more efficient and reliable. With reasonable losses, AgGaSe_2 should make an efficient and stable optical parametric oscillator. Experiments along this line are currently underway.

While a gain in excess of 13 is significant, attainment of optical parametric oscillation is the next logical step. Attainment of oscillation may require a rework of the nonlinear crystal or a change in the pump laser. Presently the AgGaSe_2 is borrowed from the Air Force and is cut and anti-reflection coated for operation with a 2.1 μm pump laser. While phasematching with the Er:YLF pump laser is possible, the incident angle is large. Large incident angles produce large losses since the anti-reflection coatings are designed both for a different wavelength and a different incident angle. Optical parametric oscillation is currently under investigation. After achieving oscillation, narrowing the spectral output of the optical parametric oscillator will be pursued.

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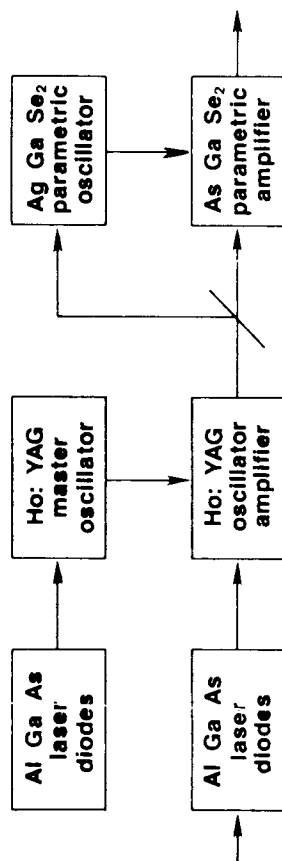
OPTICAL PARAMETRIC OSCILLATOR / AMPLIFIER



OPO PHYSICS

HIGH GAIN OPTICAL PARAMETRIC AMPLIFICATION

- Tunable mid-infrared ($2.5 \mu - 12 \mu$) laser source proposed
- A key component, the optical parametric amplifier, demonstrated
- High gain optical parametric amplification ($\times 13$) achieved



PROPOSED TUNABLE MID-INFRARED LASER SYSTEM

Database for Solid-State Laser Design

The objective is to create a prototype Computer Aided Design/Computer Aided Engineering software system for lasers (CAD/CAE for Lasers), which enables a laser designer to invent, design, assemble, and test a laser.

In addition to performing in-house work on lasers, LaRC funds contractors to design, build, and test lasers which meet LaRC specifications. With the CAD/CAE for Lasers database and software library, LaRC can invent new lasers, design lasers, review test procedures and test results, and assess proposals independent of existing or potential contractors. The database and its calculation packages represent the first such extensive compilation anywhere; requests for access have already been received from industry and academia, even prior to its becoming fully operational.

The following work has been completed:

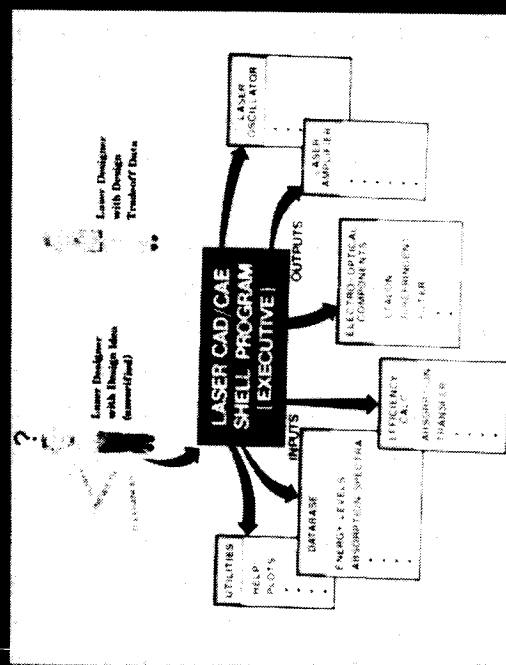
1. Developed models of electro-optical components for lasers, specifically, for etalons, birefringent filters, waveplates, and polarizers.
2. Developed a Gaussian beam ray trace/laser resonator model.
3. Developed software to calculate the absorption efficiency for lasers pumped by lasers, laser diodes, blackbody radiators, or user-supplied pump spectral profiles.
4. Created a database containing 24 tables listing all pertinent physical properties of optical, nonlinear, and laser materials.
5. Created the required software for measuring, analyzing, cataloging, and retrieving absorption and emission spectra.
6. Developed laser amplifier models that take into account both the loss at the laser wavelength and the non-uniform deposition of the stored energy.
7. Developed an analytical model to describe the amplified spontaneous emission along the axis of the laser material.

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In the future, additional spectra and tabulated data for laser materials, optical materials, and nonlinear materials will be acquired; additional electro-optical device models and additional efficiency software will be developed; laser amplifier and laser oscillator models will be added to the software system; and the executive software for prototype CAD/CAE for the lasers system will be developed. All models have been and will continue to be validated using laboratory experiments.

TECHNICAL CONTACT: P.L. Cross, LaRC (804) 864-1633

DATA BASE FOR SOLID STATE LASER DESIGN



Solving The Problem

ACCOMPLISHMENTS

- E-O component models
- Ray trace model
- Laser amplifier models
- Performance / efficiency model
- DBM software

BENEFITS

- "Paper" design of new lasers
- Review/assess test procedures, results
- Independent NASA assessment of contractor laser proposals

FY88 Annual Review of High-Temperature Superconductivity (HTS) Program at GSFC

The objective of the GSFC HTS program is to fabricate unique devices for space flight application and to understand the effects of space environment on properties and performance of HTS devices. The focus is upon thin film devices such as bolometers and accelerometers, current leads and ground straps, and devices such as magnetic bearings, and support structures that employ the effect of magnet levitation.

Application of HTS devices for space flights will result in a reduction of cooling power required for cryogenic coolers, which in turn will lead to a reduction of the launch weight and lengthening the lifetime of the cryosystems. The latter is crucial for long-term space missions.

YBaCuO superconductors have been fabricated at GSFC in the form of pellets and cylinders with properties similar to or even superior to commercial material. The capability to deposit thin films of YBaCuO (with possible expansion to the latest BiCaSrCuO compound) by electron beam evaporation is being developed. A unit consisting of three independently controlled E-beam evaporators have already been installed. The entire system will be operational within 2 to 3 months.

The capability of patterning YBaCuO thin films using a photolithographic process has been demonstrated on the films obtained from both Catholic and Howard University, which are actively collaborating with GSFC in this area. A cooperative effort is underway between GSFC and the National Bureau of Standards to build a three-part infrared bolometer. The first YBaCuO thin films on ZrO_2 substrate have already been delivered to GSFC and are undergoing intensive study.

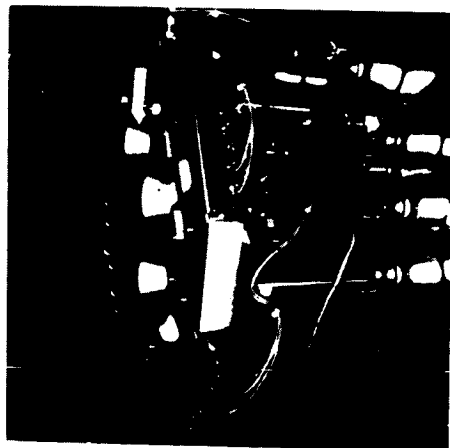
In order to ensure high quality and stable performance of HTS devices, it is necessary to establish in-house expertise in the characterization of HTS material. Measurements of electric resistance (four probe), Eddy current intensity, thermal conductivity, and infrared radiation reflectance have already been performed along with thermal gravimetric, x-ray diffraction, and metallographic analysis. The results of these measurements have established some interesting correlations.

In FY89 we will continue our work in all the previously mentioned areas, specifically thin films (1 μm) of YBaCuO will be E-beam evaporated on different substrates. Various patterns will be produced using a photolithographic process. A three-part bolometer will be built and tested. Characterization methods will be refined and expanded and a study will be initiated of the environmental effects on HTS.

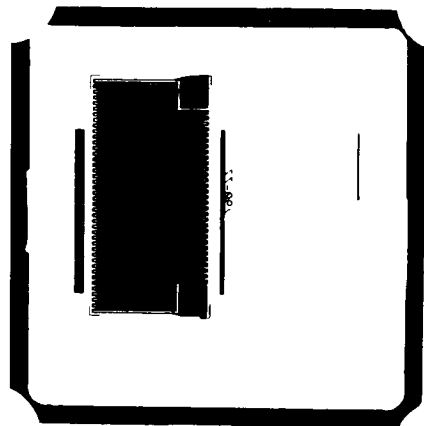
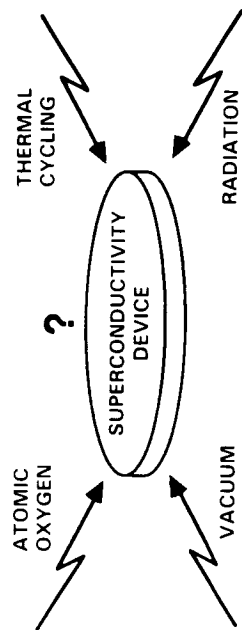
TECHNICAL CONTACT: Dr. Yury Flom, GSFC, (301) 286-3274

ENVIRONMENTAL EFFECTS ON HTS DEVICES

OSST



THREE GUN ELECTRON BEAM
EVAPORATION SYSTEM



MEANDER LINE MASK USED AT
GSFC TO ETCH A PATTERN IN
YBaCuO FILM

THREE-PART BOLOMETER

KINETIC INDUCTANCE
TEMPERATURE SENSOR

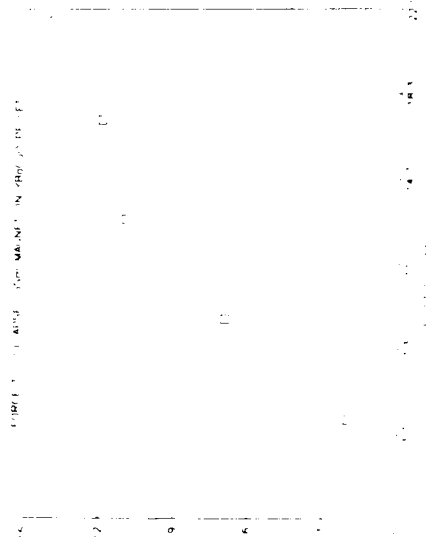
ABSORBER (30 Å Au) SUPPORTING SUBSTRATE
(1 μm DIAMOND)

PRE-AMP (SQUID)

HIGH-TEMPERATURE SUPERCONDUCTOR

T(65-75 K)

COLLAPSING FORCE
EXCLUDING MAGNET
WEIGHT





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